TIME-LAPSE VIDEO RECORDING OF INFANT SLEEP-WAKE STATES AT HOME AND IN THE LABORATORY

By

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In Memory of

Mom

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Abstract of Dissertation Presented to the Graduate School
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Time-Lapse Video Recording
of Infant Sleep-Wake States
at Home and in the Laboratory

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The present study assesses the concordance of simultaneous polygraphic and time-lapse video recordings of infant sleep-wake states, compares home and laboratory sleep-wake patterns, and assesses the night-to-night stability of home recordings.

In comparing minute-by-minute scorings of the polygraph and video, there is near-perfect agreement in the two methods for wakefulness, and fairly substantial agreement for Quiet/NREM and Active/REM sleep. When summary statistics derived from each method are compared, there is very good to moderate agreement for most parameters. The video method is also sensitive to maturational changes in sleep-wake states. However, an analysis of differences between methods revealed a systematic trend

in the scoring of sleep states. The difference was accounted for by "transition error," which is the inclination of the video to begin a period of Active sleep before the polygraph's transition to REM sleep, and to end an interval of Active sleep after the polygraph's transition to NREM sleep. It was proposed that the video method's use of motility and phasic activity in scoring sleep states may be sensitive to aspects of neurological maturation in motor control mechanisms.

In consecutive home recordings, there was considerable night-to-night stability in parameters which measured the integrity, maturity and duration of sleep, and the diurnal regularity of the sleep period. For the sleep states, only percent Active sleep was stable. Aspects of nighttime maternal caretaking and infant behavior were also described.

Laboratory recording resulted in a "first night effect," characterized by more awakenings, a greater percent of wakefulness, decreased maturity in state-to-state transitions, and curtailing of the longest sleep period. Differences were also observed in patterns of maternal caretaking. Only the percent of Active sleep and Risetime were stable across settings.

The results suggest that the time-lapse video method compares favorably with the polygraph as a technique for recording infant sleep-wake patterns. Video recording permits the unobtrusive study of sleep and sleep-related behaviors in the natural setting. Potential applications of this method in evaluating both normal sleep ontogeny and clinical sleep pathology are discussed.

CHAPTER I

INTRODUCTION AND STATEMENT OF THE PROBLEM

Introduction

The study of sleep patterns has been a focus of infant research for nearly two decades. The interest in infant sleep can be traced to early studies in the area (e.g., Kleitman and Engelmann, 1953; Roffwarg, Muzio and Dement, 1966), which described dramatic changes not only in sleep state proportions, but also in the diurnal organization of sleep and wakefulness. These early studies stimulated speculation about the function of sleep in infancy and gave rise to the notion that the changes in sleep patterning and sleep state proportions might reflect specific stages of CNS (central nervous system) maturation. In particular, several developmental changes during the early months are implicated in this view: the increase in the proportion of NREM (Non-Rapid Eye Movement) sleep (Parmelee et al., 1967; Dittrichova, 1969); the change from REM (Rapid Eye Movement) to NREM sleep onsets about two months of age (Metcalf and Emde, 1969); the ability to sustain long periods of sleep and wakefulness (Jacklin et al., 1980; Anders et al., 1983); the change from a polyphasic pattern in the neonatal period to a biphasic pattern by the end of the first year, and entrainment of the sleep-wake rhythm to other biorhythms and to the circadian rhythm of the environment (Hellbrugge et al., 1964; Anders, 1978a; Anders, 1982a).

Other developmental changes that parallel sleep-wake maturation are implicit. During the first year of life, there unfolds within an infant a transformation unlike any other in the course of life: the child matures from an altricial neonate into a mobile, social toddler with incipient language. The links between sleep-wake maturation and other aspects of development during the first year remain to be understood. Research on the implications of the milestones in sleep development, the effects of parenting practices upon achievement of the milestones, and the consequences of divergence (such as late settling or night-waking) requires the use of techniques which permit noninvasive, long-term study.

Methods of Studying Sleep in Infants

Several methods have been employed in the study of sleep-wake development in infants; each is well-suited for answering certain questions, and each has limitations and disadvantages. To a great degree, the depth of our current understanding of sleep-wake ontogeny has been enhanced by the variety of research methods.

Most studies of the changes in the 24-hour patterning of sleep-wake cycles have utilized behavior day charts or diaries kept by the infant's mother (e.g., Kleitman and Engelmann, 1953; Parmelee et al., 1964; Jacklin et al., 1980). Such studies have provided useful information about the duration and occurrence of sleep and wakefulness in the 24-hour day, and the changes in these parameters in the early weeks of life.

Stabilimeters and activity monitors have been employed by a number of investigators (Irwin, 1930; Aserinsky and Kleitman, 1955; Sander et al., 1972; Korner et al., 1974). These instruments permit continuous, long-term monitoring of activity level, crying, the duration and timing

of caregiver interventions and, to some extent, sleep and wakefulness. They are suitable for collecting such data on large numbers of infants in hospital nurseries and can be adapted for use in the home in the early weeks of life. Their major drawback for sleep studies is the problem of reliably differentiating sleep from wakefulness: without knowledge of whether an infant's eyes are open or closed, periods of alert inactivity may be mistaken for sleep. The increase in this state in the first few weeks limits the usefulness of this method to the neonatal period.

Many researchers have relied upon behavioral observations for assessing various states of sleep and wakefulness. When compared with concurrent EEG recordings, behavioral observations have been found to be a reliable method (.90 agreement) for differentiating states of sleep (Emde and Metcalf, 1970). Behavioral studies of sleep-wake state organization have been useful in characterizing individual differences and consistencies, and can be an adjunct method for following "at risk" infants (Thoman, 1975; Thoman et al., 1976). The method requires a trained, alert observer and is most practical for short-term monitoring of states (e.g., one or two interfeeding intervals).

Most studies of the changes in sleep state proportions and patterning have utilized polygraphic recording. The EEG permits the differentiation of stages of NREM sleep, and the assessment of their proportions and the presence of other hallmarks of EEG maturation (e.g., spindles and k-complexes). Most polygraphic studies in infants have been short-term recordings of two or more interfeeding intervals or a daytime nap.

The use of the polygraph with infants presents special difficulties. Parents are reluctant to bring their young infants to the laboratory for instrumentation and recording. Though harmless, the procedure is frequently upsetting for the infant. Thus, many infant EEG studies are single-recording, cross-sectional studies. In addition, the scoring of the infant polygraph requires special skill. Since the sleep stages are poorly differentiated, other physiological parameters and behavioral observations are necessary to differentiate states reliably (Anders, Emde and Parmelee, 1971; Werner, Stockard and Bickford, 1977). The different recording and scoring procedures of laboratories have hindered comparison of results. Although there have been many polygraphic studies of the premature and neonatal period, scant information exists beyond the first six months.

Recently, a number of sleep researchers have evaluated the utility of other methods of recording. Kligman et al. (1975) have utilized time-lapse movies for recording sleep-wake patterns in young infants in the home. While the method was a reliable alternative to behavioral observations, they found it expensive and somewhat obtrusive (lighting and noise) upon the normal routine of the families in the study.

Anders and Sostek (1976) compared sleep-wake states derived from time-lapse video recordings with concurrent polygraphic recordings in 2- and 8-week-old infants. They found an overall .79 correlation coefficient for all states at both ages. Anders (1978b) has adapted this method for nighttime recording of infants in the home; it was found to be nonobtrusive and well suited for long recording periods.

In sum, each method has contributed to an understanding of the sequence of stages in sleep-wake maturation. If, indeed, such changes reflect a maturing central nervous system, then this knowledge may provide insight into the underlying physiological mechanisms and a foundation for clinical evaluation and treatment of sleep disorders. The choice of a recording technique should be made given the advantages and limitations of the method for answering the particular research or clinical questions under consideration. The present study will describe further the use of time-lapse video recording in the study of infant sleep-wake patterns.

Purpose and Description of the Present Study

The objectives of the present study are 1) to assess the concordance of polygraphic and time-lapse video recording in measuring sleep-wake states in older infants; 2) to compare infant sleep-wake patterns in the laboratory and home; 3) to describe night-to-night stability in infant sleep-wake patterns.

Three related studies will address these objectives. The first study, which will assess the concordance of the polygraph and video, comprises thirteen full-term, developmentally normal infants, ranging in age from three weeks to six months, studied for one night in the laboratory using concurrent polygraphic and time-lapse video recordings. Although Anders and Sostek (1976) found fairly good agreement between these two methods up to eight weeks of age, many changes in EEG maturation occur after that age. The influence of these upon the concordance of the two methods remains to be described.

On the night prior to the laboratory recording, each of the thirteen infants was studied at home using time-lapse video recording. The second study will compare the sleep-wake patterns and state proportions in these two settings. Most infant polygraphic studies have not provided for adaptation to the instrumentation and the unfamiliar environment that is standard in adult studies of sleep. Researchers have assumed that the infant is impervious to these manipulations or, at least, that the child's sleep-wake state organization is not affected. However, several studies (Bernstein et al., 1973; Emde and Walker, 1976; Sostek and Anders, 1975) indicate that polygraphic recording in the lab disrupts sleep-wake state patterning and proportions. The thirteen infants in the present study were recorded for 24 hours; instrumentation began about 10 AM and the polygraphic recording began about noon and continued until noon of the following day. Thus, these infants had some opportunity for adaptation before the night's sleep in the lab.

The final objective of this thesis is closely tied to the second. To interpret a finding of differences in sleep between the home and laboratory, one must necessarily address the issue of night-to-night consistency in sleep-wake states. Differences between the settings could be attributable to normal, night-to-night variation. The third study comprises a second group of fifteen full-term, developmentally normal infants, aged five to six months, studied for three consecutive nights at home using the video recording method. Comparisons will address the questions of differences between the three nights and the presence of night-to-night stability in sleep-wake states.

Previous Research

The literature relevant to each of the proposed studies will be discussed separately.

Polygraphic and Time-Lapse Video Comparisons

The use of time-lapse video recording (VTR) as a method for studying sleep-wake states in infants is a fairly recent development. Two studies are relevant.

Anders and Sostek (1976) found that time-lapse video scoring of sleep-wake states corresponds favorably to polygraphic scorings in 2- and 8-week-old infants. They reported an overall .79 correlation coefficient ($p < .05$) for all states at both ages. Sleep-wake states were scored from the video recording on a minute-by-minute basis: Active-REM sleep was defined by the presence of rapid eye movements and body twitches; Quiet-NREM sleep was defined as behavioral quiescence and absence of REMs (occasional startles and rhythmic mouthing were acceptable); Transitional sleep was scored when there was uncertainty about sleep state, but occurred infrequently; Wakefulness included fussy-crying (activity with eyes open or closed and crying vocalizations), alertness (eyes open with bright gaze and motility, without vocalizations), and drowsiness (alternating activity and quiescence, eyes glazed and slowly opening and closing). The polygraphic record was coded in 20-second epochs on the basis of five parameters: EEG patterns, presence or absence of REMs on the EOG, presence or absence of muscle tone in the EMG, respiratory pattern, and the presence and type of body movements.

Using flexible criteria for determining polygraphic states (i.e., three of five state criteria must be concordant), agreement between methods was assessed:

TABLE 1.1

Product-moment Correlations of
Video and Polygraphic Sleep-Wake State Durations

	2 Weeks	8 Weeks
Active-REM Sleep	.95*	.84*
Quiet-NREM Sleep	.67	.95*
Wakefulness	.99*	.96*

*$p < .05$

[source: Anders and Sostek, 1976]

Wakefulness was highly correlated at both ages. At 2 weeks of age, Active sleep and REM sleep were more highly correlated than Quiet sleep and NREM sleep; at 8 weeks of age, the reverse was true. Though highly correlated, the VTR method tended to under-represent NREM sleep proportions:

TABLE 1.2

Mean Sleep-Wake State Proportions (%)

	2 Weeks		8 Weeks	
	VIDEO	POLYGRAPH	VIDEO	POLYGRAPH
Active-REM Sleep	38.6	25.0	29.8	29.0
Quiet-NREM Sleep	20.5	33.9	25.8	36.4
Wakefulness	40.9	39.5	44.4	33.2

[source: Anders and Sostek, 1976]

Fuller et al. (1978) examined the relationship between video-coded epochs of eye movements and body movements and polygraphically determined

states in eight premature infants. Each one-minute epoch of video recording was scored for the presence/absence of REMs and amount of body movement (e.g., no movement, some movement, a lot of movement), yielding six possible combinations of these two behaviors. Polygraphic states were determined using the flexible scoring criteria as defined by Anders et al. (1971). The records were scored in one-minute epochs with no smoothing interval. Fairly good agreement was evident for the three behavioral categories that should correspond to the polygraphic states. The following table summarizes the percentage agreement of the video codings of behavior and polygraphic scoring:

TABLE 1.3

	Polygraphic States		
Video Code:	Quiet Sleep	REM Sleep	Indeterminate Sleep
No REMs/No Movement	60%	21%	19%
REMs/Some Movement	6%	83%	11%
REMs/Lots of Movement	5%	82%	14%

The authors noted individual variability in the degree of association: two of the eight infants were consistently more deviant from the mean values than the other infants. This could not be explained by any apparent differences in their known clinical status.

The degree of association between the polygraph and video codings was determined by chi-square and contingency coefficients (3x6) for each infant. All chi-squares were highly significant ($p < .001$), and contingency coefficients ranged from .466 to .576.

To summarize, agreement between the video and polygraph is fairly good, especially when states (rather than categories of behavior) are

scored from the video tape. However, video scoring tends to under-represent the proportion of Quiet-NREM sleep.

Adult time-lapse studies

Two other time-lapse studies with adults are relevant to the description of this method of recording sleep. Using time-lapse photography (one frame every 15 minutes) and concommitant polygraphic recording, Hobson et al. (1978) found periods of postural immobility during sleep associated with the descending phase of NREM sleep. These periods of immobility generally began with Stage 2 NREM and ended with the shift to ascending NREM. The amount of immobility during the night was also positively related to subjects' ratings of the quality of sleep.

In another study utilizing both time-lapse video recording (1 frame per minute) and the polygraph, Aaronson et al. (1982) found an average of 12 postural shifts per night. It was reported that 83% of all major postural movements were associated with state-to-state transitions: 60% occurred within $\pm$ one minute of the end of a descending NREM period or the end of a REM period; 10% occurred during ascending NREM prior to the onset of a REM period; and 13% were associated with NREM interruptions of REM periods. The remaining 17% tended to occur during NREM, often during the first or last sleep cycle. Small body movements were most likely during REM, ascending NREM, and wakefulness. The findings suggested that a bimodal system of motor control is responsible for the suppression of movement during REM (inhibitory control) and NREM (disfacilitory control), and that movements are most likely to occur

when there is a switch from one mode of control to the other, namely, at the times of transitions between states.

Sleep at Home and in the Laboratory

The first night effect

In the mid and late 1960's one important focus of sleep research was the description of the sleep process in a variety of normal human subjects: children, young adults, the elderly, etc. The typical protocol of such studies was as follows: subjects were requested to come to the sleep laboratory 1 to 2 hours before their usual bedtime for instrumentation for the polygraphic recording. They were requested to abstain from medications, alcohol or caffeine drinks, and to refrain from daytime naps during the course of study. Following the application of electrodes the subject was put to bed (generally about 11 PM) in a comfortable, sound-attenuated bedroom equipped with an intercom. The subject was allowed to sleep uninterruptedly until 6 to 7AM the following morning when he/she was awakened for the removal of the electrodes and debriefing or morning performance measures.

In establishing normative data for the subjects, the first one or two nights of sleep in the laboratory were disregarded because the pattern of sleep on these nights was found to be different from the sleep of subsequent nights. This phenomenon, the adaptation or "first night" effect (Agnew, Webb, and Williams, 1969), was characterized by increased sleep and REM latencies, increased amounts of wakefulness and decreased REM percentage. These differences were believed to be a normal reaction to the novelty or "stress" of sleeping in unusual surroundings, and the sleep of subsequent nights was accepted as being

reflective of the subject's usual pattern. An important conclusion of this descriptive research was that subjects tend to sleep in a fashion that is stable or characteristic (in terms of latencies, stage percentages, etc.) from night to night.

Recent technologic advances now permit polygraphic recording in the home. Coates et al. (1979) compared the reliability of sleep recorded at home and in the laboratory. The sleep of eight subjects was recorded for three consecutive nights at home and three consecutive nights in the laboratory. In the laboratory, EEG, EOG and EMG were recorded by polygraph. Each subject slept in a private bedroom, retired at the customary bedtime, and was permitted to sleep without interruption. On the home recording nights, a technician came to the subject's home one to one and one-half hours prior to the usual bedtime to apply the electrodes and set up the recording system. The electrodes plugged into a standard headbox which connected to a transmitter attached to the subject's telephone. This permitted transmission of eight polygraphic channels to the laboratory, where the signals were recorded.

No first night effect was observed in either location. Of the eighteen variables measured, the average values of only four were not significantly correlated between settings: number of Stage 0 arousals, minutes of Stage 1 NREM, latency to REM and number of REM periods. Mean differences between settings were found for minutes of Stage 3 NREM, percent Stage 3, number of REM periods (all greater in the laboratory), and percent Stage 2 (greater at home). In addition, variances for total sleep time and sleep latency were greater in the lab.

Generalizability theory was used to estimate the observed variances in each setting. Overall, the home recordings were more reliable. At

home, there was less between and within subject variability for total sleep time, sleep latency and Stages 1 and 2. In the laboratory, minutes awake after sleep onset, number of arousals and REM were less variable. The authors concluded that although there is a close correspondence between sleep at home and in the laboratory, the reliability for some parameters may vary depending on the recording location. In designing a study, the researcher should consider the objectives of the study, the number of recordings that are feasible, the particular variables of interest, and the degree of reliability desired.

The protocol for polygraphic studies with infants has differed. As mentioned previously, parents are reluctant to bring their young infants to the laboratory for one night of recording, let alone several nights. Therefore, infant studies have usually been based upon one-time recordings without allowance for adaptation.

Bernstein, Emde and Campos (1973) investigated the problem of laboratory recording upon infant sleep. The sample consisted of fourteen four-month-old infants. Seven were observed at home for three consecutive days during the time of the morning nap; on the fourth morning these subjects were brought to the laboratory, instrumented for a "sham" polygraphic recording and observed for behavioral state; on the fifth morning these subjects were observed again in the home. The other seven subjects were observed at home for four consecutive morning naps and brought to the laboratory on the fifth day for the sham polygraphic procedure. There was a decrease in percent REM sleep on the day of the laboratory nap. In addition, they found that the nature

of sleep onset differed in the laboratory. At home, most infants began the nap with a REM onset, sometimes a very brief one. Only 1/41 naps observed in the home began with a long period of NREM sleep. In the laboratory, 3/13 naps began with a long period of NREM sleep. Wakenings from sleep also differed: the REM period prior to wakening was shorter in the lab (4.8 minutes vs. 9.5 minutes at home) and in 3/13 naps, infants wakened directly from NREM (vs. 1/41 naps in the home).

Sostek and Anders (1975) studied 24 2- and 8-week-old infants under laboratory conditions with and without polygraphic recording. The infants were observed for a continuous 24-hour period. To assess diurnal variations in states, one-third of the infants were observed beginning at one of three starting times: 10AM, 6PM, and 2AM. The 24-hours were divided into six 4-hour periods: 1) two 4-hour periods when the infants were brought to the laboratory and recorded by means of time-lapse video tape only (Pre 1 and Pre 2); 2) three 4-hour periods with polygraphic recording in addition to the video (Poly 1,2,3); and 3) a final 4-hour period after removal of the polygraphic electrodes (Post). There were no significant changes in the amount of sleep across periods, but for the 8-week-old infants there was decreased REM percent during polygraphic recording (Poly 1 and 2). A slight increase in REM percent in Poly 2 suggested a possible REM rebound. Sleep latencies were significantly shorter following electrode application (Poly 1) and removal (Post). Changes in wakeful activity at both ages consisted of decreased alertness and increased fussy-cry during pre-adapted periods (Pre 1 and Poly 1), and increased drowsiness following electrode application (Poly 1) and following electrode removal (Post). Changes in waking activity did adapt following "stress" periods: during adapted periods (Pre 2 and

Poly 2,3) diurnal variations were found at both ages and were more pronounced for the 8-week-olds.

Kligman, Smyrl and Emde (1975) studied a group of 6 infants longitudinally at weekly intervals from 7 to 25 weeks of age by means of time-lapse movies in the home during morning nap periods. Contrary to laboratory findings of consistent NREM sleep onsets by 2 months of age, this study found no abrupt or absolute age of change to NREM onsets: some infants had one or more REM sleep onsets after having had a NREM onset. Three of the six infants observed had consistent (3 or more consecutive) NREM sleep onsets by 16 weeks of age. The authors suggest that laboratory conditions may be responsible for the reported change to NREM onsets by 2 months and the seeming lack of variability in this response.

Emde and Walker (1976) have also expressed the concern that laboratory effects may confound observed age-related changes in sleep-wake patterning and sleep state proportions. In a longitudinal polygraphic study of morning naps during the first year of life, they found that after one month of age nap periods were significantly shorter in the laboratory than maternal reports of the infants' morning naps at home. They also found an unexpectedly small proportion of REM sleep (16%) at one year of age.

These findings suggest that laboratory instrumentation and recording do affect sleep in infants. The effect is characterized by decreased percent REM sleep, more frequent and longer NREM sleep onsets, decreased sleep length (after one month of age), more frequent awakenings from NREM and shortened REM periods prior to awakening. In addition, there is an initial disruption of diurnal variation in waking states: while

waking states appear to adapt after a fairly brief time, there is the suggestion from the Sostek and Anders study that the adaptation of sleep states to polygraphic recording requires more than 12 hours.

Stress and neonatal sleep. It may be useful to discuss the few studies that directly address the question of the effects of stress upon neonatal sleep.

There are four relevant studies. The first was a study of the effects of circumcision upon sleep in neonates. Emde, Harmon, Metcalf, Koenig and Wagonfeld (1971) studied a group of ten infants for a continuous 10-hour period of polygraphic recording following routine circumcision by the Plastibel technique. This procedure has an acute component (midline foreskin incision) and a chronic phase (ischemic necrosis of the foreskin). In comparison to their pre-circumcision baseline recording and a control group of 10 uncircumcised infants, the circumcised infants evidenced shorter NREM latencies, an increased number of NREM periods and more extremely long NREM periods. The authors discuss these findings relative to Engel's theory of response to stressful stimulation (1962). This theory proposes two modes of response to stress: a response of increased vigilance/activity ("flight" or "fight"), and a response of increased sensory threshholds/ decreased activity ("conservation-withdrawal"). Since the response of escape from the stress was unavailable to the infants, they showed the conservation-withdrawal response suggested by the increase in NREM sleep.

In another study of circumcision (Anders and Chalemian, 1974), infants were observed behaviorally for three 1-hour periods: 1) a

baseline, pre-circumcision period following feeding; 2) a period immediately following circumcision; and 3) a recovery period following the next feeding. The circumcision technique was an acute procedure lasting about 15 minutes. The changes these authors found were limited to wakeful states: increased fussy-crying during the post-circumcision period. Decreased sleep latencies were observed during the recovery period, but there were no changes in NREM sleep.

A recent study has attempted to investigate the conflicting results of the above studies (Sahatjian and Hicks, 1981). The sleep states of circumcised infants were compared to a noncircumcised control group. The circumcision technique in this study was the acute (i.e., Plastibel) method, completed between 8 and 9 AM. Both groups of infants were observed behaviorally for two one-hour intervals: at 10 AM, following the morning feeding and, again, at 2 PM following the afternoon feeding. The findings tended to confirm the Emde study: the circumcised group evidenced some increase in Quiet sleep during the first observation period, and a significant increase in Quiet sleep during the second. The authors proposed the concept of a gradient of increase in Quiet sleep proportions following a stressor.

Two other studies describe a different type of stress: sleep deprivation in newborns (Anders and Roffwarg, 1973). The first focused on selective interruption of REM and NREM sleep. Sleep state was determined by polygraphic recording. Infants were divided into three groups: REM disturbed, NREM disturbed and baseline controls (uninterrupted sleep). The REM and NREM disturbed groups were awakened from the specified state during the course of one interfeeding interval, and were then allowed to sleep undisturbed during the next interfeeding interval

(recovery period). Total sleep time during the recovery period was increased for both groups in comparison to baseline controls. For the REM disturbed group, there was increased REM and NREM during the recovery period, but it did not differ significantly from the baseline group. However, the NREM disturbed group did exhibit significantly increased NREM sleep compared to the baselines. Furthermore, disturbance of a particular state of sleep did not seem to decrease the proportion of sleep in that state: during REM disturbance the proportion of REM sleep (REM/TST) was greater than for the undisturbed baseline group and, similarly, during NREM disturbance the proportion of NREM sleep was greater (n.b.: these did not reach significance, however). This was due to the fact that when aroused, the infants tended to return to the pre-arousal state repeatedly. Likewise, during recovery periods, NREM disturbed infants evidenced greater percent NREM than REM, and REM disturbed infants evidenced greater percent REM than NREM.

The second study investigated total sleep deprivation. On day 1, infants were instrumented for polygraphic recording and allowed to sleep without interruption for two interfeeding intervals. On day 2, the same infants were kept awake for one interfeeding interval, then allowed to sleep undisturbed for two interfeeding intervals (recovery 1 and 2). During the first recovery period total sleep increased a mean of 19%, then returned to baseline levels during recovery period 2. The proportional relationship of REM to NREM was similar in all periods: percent REM sleep exceeded percent NREM, although the amount of NREM sleep in the first recovery period was significantly higher than baseline. In examining the first 30 minutes of recovery 1, they found an increased proportion of NREM sleep ($p < .05$). Recovery periods were

also characterized by more frequent (though n.s.) NREM sleep onsets and a decreased sleep latency ($p < .05$).

The authors concluded that the capacity to compensate for REM and NREM deprivation exists in young infants. The tendency to return to the pre-arousal state suggests a "tenacity" of sleep state. It also appears that NREM sleep is more sensitive to environmental perturbations and may exhibit a greater tendency for compensation than REM.

Summary. The results of these studies complement those on the effects of polygraphic instrumentation. With regard to waking activity, the infant responds with increased fussy-crying, decreased alertness and increased drowsiness. During the initial period of the stress, the developing diurnal variations in waking activity are disrupted (at least up to 8 weeks of age).

With regard to sleep, younger infants appear to maintain the same total sleep time during the stress period as during baseline (unless the stress resulted in an inordinate amount of wakefulness). Older infants appear to curtail or shorten their sleep period. Sleep latency is decreased during stress periods. In the case of a strong stress for younger infants, a NREM sleep onset may occur or the latency to NREM may be decreased. For older infants, in whom NREM onsets are more likely by dint of maturation, the initial NREM onset period may be prolonged.

The proportions of REM and NREM differ during stress periods. Percent REM is likely to be decreased in proportion to the degree of stress. NREM percent is likely to be increased. For younger infants, during a strongly stressful period, one would also expect more NREM

periods and more long NREM periods than during baseline.

Wakenings from sleep also appear to differ during stress conditions. There are more wakenings from NREM sleep, while wakenings from REM sleep occur sooner after the onset of the REM period than during baseline periods.

Compensation of decreased REM and NREM sleep appears to be fairly rapid or immediate in young infants. For older infants, compensation may be deferred until the next sleep period, e.g., the infant whose morning nap is curtailed by a stress might be expected to compensate for decreased REM and/or NREM sleep during his afternoon nap or night's sleep.

Night-to-Night Stability in Sleep

Most of the research on night-to-night stability in sleep has been conducted in sleep laboratories with older children and adults. Several studies address this topic (Webb and Agnew, 1969; Schmidt and Kaelbling, 1971; Moses et al., 1972; Roth et al., 1973; Feinberg, 1974; Clausen et al., 1974; Chernik et al., 1975). All report fairly stable group means in sleep stage proportions across nights.

However, several of the studies noted a lack of night-to-night consistency within subjects in many sleep parameters, and average values reported in the literature belie both inter- and intra-subject consistency. Clausen et al. (1974) found a mean REM cycle duration of 100 minutes, similar to other studies. They emphasized, however, the mean REM cycle duration for individuals ranged from 57 to 188 minutes, and between nights correlations ranged from a non-significant -.19 to

a significant .84. They also reported less variability within than between subjects (using ANOVA) for percent REM, REM latency, REM duration, number of eye movements, percent stage 4, and percent awake. Standard deviations within subjects across four nights were also consistently smaller than between subjects. Similarly, coefficients of concordance were significant for total sleep time in addition to the aforementioned parameters, suggesting this array of variables is characteristic for the individual.

The question of sleep stability in infants has been approached in a different way. Consecutive nights of polygraphic recording with infants are lacking, in part due to parental reluctance to consent to the requirements of long-term recording and the intrusive nature of instrumentation. The description of sleep stability in infancy is more often based on state observations of daytime naps or parent diaries and focuses on global aspects of sleep such as daily amount, duration, characteristics of state organization, and the establishment of a diurnal sleep-wake rhythm. These studies often relate sleep patterns to other individual characteristics, such as temperament, state organization, type of feeding or developmental status.

Long-term longitudinal studies have suggested that stability in sleep patterns may be related to developmental outcome. Thomas, Chess and Birch (1968), in their study of 141 children from birth to ten years of age, reported that children who exhibited difficulty in establishing regularity in patterns of feeding, sleeping and bodily functions were more likely to develop behavior problems in later childhood.

In the neonate, sleep is distributed evenly across the 24-hour day in 3- to 4-hour periods. By the end of the first month, there are

day-night differences in sleep and wakefulness (Hellbrugge et al., 1964). Gradually, periods of night-time sleep become consolidated into longer intervals with shorter intervening wakeful periods.

A milestone in sleep maturation, of great importance to parents, is sleeping through the night or "settling." Moore and Ucko (1957) defined this as sleeping from midnight to 5 AM without waking for at least four weeks. They concluded from parent diaries that 70% of infants settle by three months of age, 83% by six months and 90% by nine months. Early settling was positively correlated to mature, normal development, and was not related to type of feeding.

Fifty percent of the infants who had settled evidenced night-waking (i.e., waking between 12-5 AM at least once weekly for four weeks) later in the first year. Night-waking was related to disruptions or stresses in the environment, e.g., illnesses, trips, etc. Carey (1974) found night-waking in 25% of infants between six and twelve months of age. A low sensory threshhold, determined by his temperament scale, was correlated with night-waking. A later study (Carey, 1975) found a higher incidence of night-waking in breast-fed babies six to twelve months old: 52.4% of breast-fed babies were night-wakers vs. 19.6% of bottle-fed babies.

Other studies have examined daily amount and duration of sleep. Moss (1967) reported a positive (nonsignificant) correlation in total sleep per day between three weeks and three months of age. Jacklin et al. (1980) studied sleep-wake durations longitudinally from six to twenty-six months through parent diaries. A 24-hour sleep-wake diary was completed twice, about one week apart, at six, nine, twelve, eighteen and twenty-six months of age. Moderate stability ($r = .41$ to

.76) was evident at each age for the longest period of sleep per day. Total sleep per day (r = .37 to .91) and the longest period of wakefulness (r = .37 to .63) were moderately stable between nine and twenty-six months. In a related study (Snow et al., 1980), the frequency of wakeful distress was positively correlated with frequency of sleep-wake transitions at six, nine and eighteen months, suggesting that fussy infants were more likely to exhibit immaturity in sleep development.

Some studies have examined stability of state characteristics and organization. Thoman (1975; Thoman et al., 1976) reported individual consistency between morning and afternoon naps in the proportion of five sleep-wake state clusters in day-old infants. Cluster I was composed of Quiet Sleep with regular respiration and Alert Inactivity, both highly organized, mature states in terms of physiological functioning. Cluster II included Active Sleep with REMs, Waking Activity and Crying, states of high arousal. Cluster III included Active Sleep without REMs, Drowsy and Indefinite, all transitional states. Cluster IV was defined by Quiet Sleep with irregular respiration. Cluster V was composed of Active Sleep with REMs and Active Sleep with Dense REMs. These last two clusters seemed to be unique, individually reliable states. For individual infants, morning and afternoon profiles of these five clusters were similar.

The profiles also confirmed observers' subjective ratings of how "well" or "poorly" organized an infant's states were. "Well-organized" infants spent more time in Cluster I, little time in Cluster III and showed evidence of cycling of states. In a related study, similar consistencies were found to persist over the first five weeks of life.

Dittrichova and her colleagues (1976), in examining state-related behavior during paradoxical sleep, found individual stability over the first five months for the frequency of REMs, presence of regular EEG activity and incidence of body movements. Respiratory rate during Quiet sleep also showed stability for individuals.

In sum, although night-to-night studies are lacking, infants exhibit some degree of stability in diurnal rhythmicity, sleep duration and state characteristics.

CHAPTER II

METHODOLOGY AND PROCEDURES

Home/Laboratory and Polygraph/Video Studies

Subject Selection

Thirteen normal, full-term infants, six males and seven females, were the subjects for two studies. The infants were normal controls in an ongoing study of infant sleep apnea and Sudden Infant Death Syndrome (SIDS) conducted by Dr. Christian Guilleminault and his colleagues in the Stanford Sleep Disorders Center. The following table displays the sample by age and sex:

TABLE 2.1

Age and Sex of Sample Infants

	Age in Weeks			
	3	12	18	24
Male	1	1	3	1
Female	2	2	1	2

The infant's family was contacted by phone, and the purpose and procedures of the present study were described. All the families expressed interest in the study and consented to participate. The home recording was scheduled for the night prior to the day of laboratory recording.

Recording Procedures

Time-lapse video equipment

The time-lapse video recording system (VTR) is compact and easily transported. It consists of a Panasonic video camera (model WV-1050) equipped with a Newvicon tube for recording in infrared/low illumination; a Panasonic Variable-Speed Time-Lapse Video Recorder (model NV-8030); a QSI automatic time-date generator which displays the date and time of recording on the video tape; an 11" Sony TV monitor; a small closed-box light source with an infrared filter; and a microphone placed near the infant's crib which allows crying episodes to be heard during playback.

The VTR time reduction is 18 to 1; that is, the VTR will record for 18 hours on a standard one-hour (7") reel of video tape. An internal electronic switching mechanism controls the recording speed. Approximately 3.3 frames per second are recorded in the 18:1 recording speed (versus 60 frames per second if a recording were made at normal speed, without time-lapse).

Recording procedure in the home

In the afternoon of the day before the infant was scheduled for the laboratory polygraphic recording, the time-lapse video equipment was brought to the infant's home. The camera was placed on a tripod near the head of the infant's crib and focused on the bed. The camera is connected to the recorder by means of a 20-foot video cable, so the recording equipment may be placed at a distance from the crib or in the hallway outside the room, if possible.

The infrared light was placed in a corner of the infant's room and

directed toward the walls or ceiling of the room; the reflected light provides adequate illumination for a clear, bright recording.

At each filming an infant status interview was completed to assess illnesses, injuries, stresses, developmental achievements and typical sleep-wake patterns during the week prior to and the day of the recording (see Appendix I).

With the equipment in place and operating properly, the VTR was activated and the experimenters left. The following morning the experimenters returned to remove the equipment. Notes were made on the infant status form regarding the mother's report of the night's sleep. All of the mothers reported the night had been representative, and felt the recording equipment had not intruded upon their usual routine.

Recording procedure in the laboratory

The day of the polygraphic recording the infant was brought to the Clinical Research Center at Stanford Hospital about 10 AM for instrumentation for the 24-hour polygraphic recording, which began about noon.

The polygraphic recording includes electroencephalogram (EEG) C_3/A_2, C_4/A_1 from the 10-20 International System, electro-oculogram (EOG), chin electromyogram (EMG), and electrocardiogram (ECG, lead II). Respiration is measured using a thermistor for air flow, and strain gauges for abdominal and thoracic effort. The recording took place in a comfortable, standard size 2-bed hospital room equipped with the polygraph, an infant hospital crib and a standard hospital bed. The infant's mother and an EEG technician were usually present throughout. Meals were served in the room. A small high-intensity lamp near the

polygraph provided subdued illumination during the nighttime portions of the recording. The electrode bundle was plugged into a portable electrode box, so the child was free to be carried about the room without being disconnected from the polygraph.

In the late afternoon the video equipment was brought to the hospital room and set in place in the same fashion as at home. Relevant portions of the infant status interview were also completed at this time. The following morning the experimenter returned to retrieve the equipment and obtain a maternal report of the infant's sleep.

Coding of Video Tapes and Polygraphic Records

Coding of video sleep-wake states

Since the time-lapse recording is played back at normal speed, all movement is "speeded-up." Small movements, smiles, grimaces and phasic twitches are accentuated, and REMs can be seen clearly under closed lids. The entire night's sleep can be viewed in approximately one hour.

Scoring is similar to conventional methods for behavioral observation. The criteria for sleep and waking states are based upon those described in the Brain Information Service Manual of Standardized Terminology, Techniques, and Criteria for Scoring States of Sleep and Wakefulness in Newborn Infants (Anders, Emde and Parmelee, 1971).

Four states are scored from the video tape:

State 1 - Quiet Sleep is characterized by absence of gross motor activity, except for occasional jerks or startles. Rhythmic mouthing may be present. The eyes are closed; vocalizations are absent. Respiration (if discernible) is regular.

State 2 - Active Sleep is characterized by frequent body movements, phasic twitches, smiles, sighs, brief cries and rapid eye movements (REMs). Eyes are closed, except for occasional transient openings.

State 3 - Awake is characterized by the infant's eyes being open and alert. The infant may be lying quietly, moving about and/or crying.

State 4 - Out-of-Crib is scored when the infant has been removed from the crib for soothing, feeding or other caretaking interventions.

The scoring of states begins when the infant is first placed into the crib. The infant's bedtime and the time of any state changes are noted using the time that is incorporated in the video picture (vid., Appendix II includes a sample sleep coding form). The sleep states (except for sleep onsets and awakenings from sleep) have a minimum 5-minute duration: a period of Active sleep containing an interval of quiescence of 4 minutes or less is scored as continuous Active sleep. To begin a period of Active sleep, the infant must meet one of two criteria: 1) REMs must be present, or 2) two movements must be observed within a three-minute interval, and a third movement must be observed within five minutes of the second movement. Thereafter, a five-minute rule applies: an interval of Active sleep ends when no REMs are observed, and movements and phasic activity occur less frequently than every five minutes. At sleep onset and awakenings from sleep, the onset state or ending state may be less than 5 minutes; since these transitions are known to change with age an exception to the 5-minute rule is made. Wakefulness and Out-of-Crib (OOC) are scored on a minute-by-minute basis.

In addition to the four states, the times of any maternal interventions (i.e., mother checking the baby, covering with a blanket, etc.), any "props" that are used to soothe the baby (e.g., toy, bottle, pacifier, etc.) and the baby's sleeping posture are noted on the scoring sheet.

Reliability of video scoring. Interrater reliability was assessed by the kappa coefficient (k) (Cohen, 1960). Agreement in home and lab scorings was assessed separately. In both cases, two tapes were selected at random, and a 4-hour segment from each tape, again chosen at random, was scored independently by a second research assistant experienced in the coding of video recordings of sleep-wake states. Overall agreement for the lab scoring was .83 (a three-week-old infant) and .86 (a six-month-old infant). Reliability for Quiet sleep was .92 and .82 (respectively); for Active sleep, .82 and .79; for Awake, .42 and .86; and for Out-of-Crib, .96 and .97. Thus, reliability was very good, except for Awake in the younger infant. This segment contained several brief awakenings, and the raters disagreed to some extent upon the onset and ending of the wakefulness, resulting in the relatively low agreement. Overall agreement for the home scorings was .95 (a three-month-old) and .94 (a six-month-old). Reliability for Quiet sleep was .94 for both; for Active sleep, .94 and .92; for Awake, 1.00 and .66; and for Out-of-Crib, 1.00 for both.

Coding of polygraphic recordings

The polygraphic recordings were scored independently by members of the Infant Sleep Apnea research team. The polygraph is scored epoch by epoch (each epoch = 30 seconds) according to criteria described by Souquet et al. (1976). For infants under three months of age, each epoch is coded for five parameters: EEG pattern, presence or absence of REMs on the EOG, presence or absence of muscle tone in the EMG, respiratory regularity, and presence or absence of body movements. Using flexible criteria (i.e., three of five parameters must be

concordant), each epoch is then assigned one of five possible state scorings: Indeterminate sleep, Quiet sleep, REM sleep, Movement Time, and Awake. For infants three months of age and older, a modified adult method is used. Based upon the EEG and EOG, one of six possible scorings may be assigned to an epoch: NREM Stage 1, Stage 2, Stage 3, REM, Movement Time, or Awake.

After each record is assigned the state scorings, it is analyzed by means of a Sleep Cycling Program (Nagel et al., 1982), a computer program designed to group the epoch-by-epoch scorings into stage sequences or "ordered stages" (vid., Appendix IV). There are five possible ordered stages for infants under three months of age: Indeterminate sleep, Quiet sleep, REM sleep, Transitional sleep, and Awake. For infants three months of age or older, there are six possible ordered stages: Stage 1, Stage 2, or Stage 3 NREM, Transitional sleep, REM sleep, and Awake. Transitional sleep is roughly analogous to ascending NREM in adults: it is usually a brief interval (5 minutes or less), sometimes present, between the end of the deepest stage of NREM achieved in a sleep cycle and the onset of REM. In this sample of infants, it often consists of Stage 1, but sometimes contains epochs of other NREM stages, wakefulness, movement time and/or REM.

It should be noted that the sleep cycling program smoothes brief intrusions of wakefulness less than 10 minutes in duration. Moreover, the scoring of wakefulness and movement time overlap to some extent: consecutive epochs of movement time are coded as wakefulness on the polygraphic coding sheets. The assumption made is that movement time in excess of one epoch constitutes wakefulness. As will be described later, this compromised comparisons between the methods to some degree.

Night-To-Night Stability Recordings

Subject Selection

Fifteen infants, five to six months old (median age = 182 days; range: 150 to 194 days), were recruited from the logbook of the Stanford Hospital Newborn Nursery. Criteria for inclusion in the study were uneventful, full-term pregnancy and perinatal course; Apgars of 7 or above at one minute and 8 or above at five minutes; normal status on the neonatal neurological examination; and no subsequent medical or developmental problems.

Each family was initially contacted by phone. The purpose of the study and the procedures involved were explained. If consent was obtained, a convenient date for the recordings was arranged.

The sample was composed of seven males and eight females; five infants were first-born, ten were latter-born. With regard to sleep history, they were fairly representative, according to the Moore and Ucko (1957) study. Eleven of the fifteen (73%) had settled by the time of the study. The age of settling ranged from three to twelve weeks (median = 8 weeks). Three of the eleven (27%) were persistent night-wakers (i.e., night-waking for one month or more prior to the study). Three other infants were recent night-wakers (i.e., for less than one month). Two of these had developed night-waking secondary to a mild upper respiratory infection prior to the study. Although the illness had resolved several days before recording, both mothers reported the night-waking continued.

Recording Procedure

The time-lapse video equipment was brought to the infant's home and set in place as described in the previous section. An infant status interview was completed and a brief developmental history was taken. The equipment was left in the home for three consecutive days. Parents were instructed how to turn off the equipment in the morning, after the infant had awakened for the day.

In the afternoon of the second and third days, the experimenter returned to the home to change the video tape and reactivate the recorder. The experimenters returned on the morning following the third night of sleep to remove the equipment.

Coding of Video Sleep-Wake States

The sleep-wake states were coded by the method described previously.

Description of Sleep-Wake Parameters

The following section describes the sleep-wake variables that were measured in the present study, and how each was derived. Some of the parameters used in the polygraphic and video comparisons of the laboratory recording differ slightly from the two studies of sleep-wake patterns in the home, and will be defined separately.

Comparison of Polygraph and Video Sleep-Wake Parameters in the Laboratory

During the laboratory recording night, the sleep-wake parameters that were chosen for comparison are those that are frequently of interest to researchers studying sleep in infants. To assess agreement between methods, intervals when the infant was Out-of-Crib during the laboratory recording night were excluded from these analyses. These periods will be described separately in Chapter III, page 62. This section will describe how each of the sleep-wake parameters was derived.

Total number of awakenings

The video method scores wakefulness minute-by-minute. Thus, the total number of awakenings during the night comprised all discrete awakenings of one minute or more duration, following the first onset of sleep up to, but not including, the final awakening the next morning.

The sleep cycling program (described in Appendix IV and earlier in this chapter, Coding of Polygraphic Recordings, page 30) which creates the ordered polygraphic stages smoothes brief intrusions of wakefulness less than 10 minutes in duration. Thus, to permit comparison between the two methods, any period of wakefulness of one minute or longer, recorded by the polygraph, was counted as an awakening within the ongoing ordered stage. The total number of awakenings for the polygraph was determined in the same fashion as above, from the first onset of sleep up to, but not including, the final awakening.

Number of Quiet/Nrem and Active/Rem sleep onsets

A sleep onset was defined as a transition from wakefulness (as defined above) to either sleep state. The number of NREM sleep onsets

for the polygraph was the total of transitions from wakefulness to Stage 1, 2, or 3 NREM. The number of REM sleep onsets was the total of transitions from wakefulness to REM. The number of Quiet or Active sleep onsets was determined accordingly.

Total sleep time and longest sleep period

The total recording period (TRP) is defined as the number of minutes from the time the infant is placed in the crib for the night's sleep and has at least one complete sleep cycle (a period of Active sleep followed by a period of Quiet sleep, or vice versa) before being removed for caretaking or a feeding, and the time of the child's final removal from the crib the following morning.

Total sleep time (TST) is defined as the total minutes of sleep observed within the total recording period.

The longest sleep period (LSP) is defined as the longest interval of uninterrupted sleep (in minutes) during the total recording period.

Sleep-wake state proportions

The proportions of Wakefulness, Quiet/NREM sleep, and Active/REM sleep were calculated by dividing the sum of minutes of each state by the total recording period less the minutes spent out-of-crib.

Duration of the first Quiet/NREM period

Duration of the first Quiet/NREM period is defined as the length in minutes of the first period of Quiet/NREM sleep observed following an infant's sleep onset or placement in the crib. For those five infants who were put to bed in the midst of a period of Quiet/NREM sleep, the subsequent period of Quiet/NREM sleep was counted as the first period.

Sleep cycle duration

Sleep cycle duration (in minutes) was determined in one of two ways, depending upon the infant's age. For the three-week-old infants, it was calculated by averaging the intervals defined by the onset of REM (or Active sleep, for the video) to the onset of the subsequent REM (or Active sleep) period. For older infants, it was derived by averaging the intervals defined by the onset of NREM (or Quiet sleep) to the onset of the subsequent NREM period.

Comparison of Video Sleep-Wake Parameters in the Home and Laboratory

A common set of parameters is used for the chapters which describe night-to-night stability and compare sleep-wake patterns at home with those in the laboratory. Parameters were chosen which would summarize and characterize a night's sleep for an infant. These include aspects of its maturity, diurnal placement, and sleep-wake state composition. The following section describes how each is defined.

Total awakenings

The total number of awakenings during the night comprises all discrete awakenings of one minute or more duration following the first onset of sleep up to, but not including, the final awakening the next morning.

Total sleep time, longest sleep period
and minutes of the longest sleep period in 12-5 AM

The total recording period (TRP) is defined as above, as the number of minutes from the time the infant is placed in the crib for the night's sleep and has at least one complete sleep cycle (a period of

Active sleep followed by a period of Quiet sleep, or vice versa) before being removed for caretaking or a feeding, and the time of the child's final removal from the crib the following morning.

Total sleep time (TST) is defined as the total minutes of sleep observed within the total recording period.

The longest sleep period (LSP) is defined as the longest sustained interval of sleep in minutes during the total recording period.

The minutes of the longest sleep period in 12-5 AM (LSP 12-5) attempts to capture an aspect of the diurnal entrainment of the child's sleep (Anders, 1982b). As described in the literature review, the infant's nighttime sleep periods gradually become consolidated into long intervals with short intervening periods of wakefulness. Conventionally, the child is described as "settled" when he sleeps without waking during the hours of 12 to 5 AM, the probable time of his parents' sleep. The LSP 12-5 is a measure of the degree of synchrony between the infant's most sustained sleep and the parents' sleep period. It is expressed as a percentage, and is calculated by dividing the number of minutes of the longest sleep period observed during the hours of 12 to 5 AM by 300 (i.e., the number of minutes between 12 and 5 AM).

Sleep cycle duration

Sleep cycle duration (in minutes) was determined in one of two ways, depending upon the infant's age. For the three-week-old infants, it was calculated by averaging the intervals defined by the onset of Active sleep to the onset of the subsequent Active sleep period. For older infants, it was calculated by averaging the intervals defined by the onset of Quiet sleep to the onset of the subsequent Quiet sleep period.

Sleep-wake state proportions

The proportions of Wakefulness, Quiet sleep, Active sleep, and Out-of-Crib were derived from the semi-Markov analyses, by dividing the sum of minutes of each state by the total recording period.

Bedtime and risetime

Bedtime is defined as the starting time of the total recording period. Risetime is defined as the time of the child's final awakening the next morning.

Transition probability index (TPI) and holding time index (HTI)

The Transition Probability Index and the Holding Time Index are summary parameters which reflect the maturity of the state-to-state transitions and holding times for a night's sleep (Anders et al., 1983; Bowe, 1981). These are derived by means of a computer program based on a semi-Markov model of sleep-wake state development. The following section will describe this procedure in greater detail.

The semi-Markov model is a mathematical model that can be useful for studying phenomena which can be characterized as mutually exclusive "states" which are occupied for varying durations (Howard, 1971a; Howard, 1971b). The building blocks of the model are the changes from state to state (transitions) and the lengths of time spent in the given states between such changes (holding times).

Suppose an infant begins a night's sleep by being placed into his crib awake. After a time, he falls asleep, beginning with a period of Active sleep. This state change is referred to as a "transition," in this instance, an "Awake to Active sleep" transition. Transitions are

distinguished by the state the infant is now occupying (e.g., Awake) and his "destination" state (e.g., Active sleep). Now, suppose it has taken this infant 20 minutes to fall asleep. This 20 minutes is referred to as a "holding time," in this case, an "Awake to Active sleep" holding time. Holding times are distinguished in the same way as transitions, by the state now occupied and the destination state. In this manner, an entire night's sleep can be described as a sequence of transitions and holding times. For the four states described above, twelve types of transitions and holding times are possible:

...and his next transition is to state j:

Infant is in state i:	QS	AS	AW	OOC
QS		P_{ij} $h_{ij}^{(T)}$		
AS				
AW				
OOC				

where

P_{ij} = the probability of making a transition from state i to state j.

$h_{ij}^{(T)}$ = holding time density function given the infant is in state i and will make the next transition to state j.

$i \neq j$

FIGURE 2.1

Transition Probability and Holding Time Matrix

The above table is referred to as a transition probability and holding time matrix. Since it has been shown in studies of sleep in older children and adults that the proportions of NREM and REM sleep differ by the time of night (i.e., time elapsed since sleep onset), separate matrices are constructed for three "phases" of sleep: phase 1 ends with the first transition 180 minutes after the beginning of the night's sleep; phase 2 is defined as the time between the end of phase 1 and the first transition 360 minutes after the beginning of the night's sleep; and phase 3 is defined as the time between the end of phase 2 and the infant's final awakening in the morning. Thus, the three phases divide the night's sleep approximately into thirds. The reader is referred to Appendix II which presents a scoring sheet for infant Bu and the transition probability and holding time matrices by phases of night generated by the semi-Markov programs.

The usual summary statisitics of sleep-wake patterns can be derived as functions of the model's fundamental parameters, the transition probabilities and holding times (Bowe, 1981):

Sleep Terminology	Semi-Markov Terminology
Percent of time in each state	Limiting transition probability
Sleep latency	First passage time
Sleep onset stage	Probable trapping state
Sleep period	Mean recurrence time
Number of stage shifts	Number of transitions
Sleeping through the night	Probability of zero transitions to the awake state in time T
Number of active cycles	Mean number of active renewals

A semi-Markov model conceives of the phenomenon being studied as stochastic or probabilistic. An observed statistic, for example a given holding time, is a single realization of the possible set of outcomes.

Anders et al. (1983) have used sleep-wake data from 40 full-term, normal infants studied longitudinally during the first year of life to generate four semi-Markov models of sleep-wake maturity based on the observed age-related changes in sleep during this time. Each age-group model represents a particular level of development in sleep-wake patterns. Thus, a given infant's pattern of transitions and holding times can be compared to each of the four models. The probability that the infant's transitions and holding times could be derived from each model is computed; the resulting vector of four probabilities is then weighted and summed to form "maturity" scores, one indicating the relative maturity of the child's holding times (Holding Time Index or HTI), and the other indicating the relative maturity of his pattern of transitions (Transition Probability Index or TPI).

A low TPI (immature pattern of transitions) would be obtained if an infant wakened repeatedly, was removed from the crib when he woke, and had Active sleep onsets. Conversely, a high TPI (mature pattern) would be obtained if an infant had Quiet sleep onsets and did not waken during the night, or if he did waken, could return to sleep without being removed from his crib. Maturity in the Holding Time Index reflects a temporal patterning of sleep <u>within the night</u>, characteristic of older children and adults (namely, higher proportions of NREM sleep and relatively little REM sleep in the first part of the night), which emerges gradually over the course of the first year of life. This is exhibited in long Quiet sleep holding times and short Active sleep holding times in the first and second phases of sleep. An infant with a low HTI would have relatively short Quiet sleep holding times and long

Active sleep holding times in the first two phases of sleep. Conversely, an infant with long Quiet sleep holding times and short Active sleep holding times in the first two phases, would obtain a high index.

The indices were formulated to range from a minimum of 2.0 to a maximum of 20.0. Their important advantage is that all the observed data for a given infant's night of sleep are utilized since each transition and holding time is taken into account in the calculation of the respective indices. Appendix III provides a table of the median indices at each of the ages in the Anders' study.

CHAPTER III

POLYGRAPHIC AND VIDEO CONCORDANCE

Introduction

This chapter compares the concordance between the polygraphic and video scoring of sleep-wake states. The analyses focus solely on the laboratory recording night for the thirteen infants who were studied both at home and in the laboratory (described in Chapter I, Purpose and Description, page 5, and Chapter II, Subject Selection, page 25). The analyses will be of interest to researchers familiar with infant polygraphic recordings who may want to consider the time-lapse video method as an alternative in their studies of infant sleep-wake states. The intent of this chapter is to give an indication of the degree of comparability between the two recording methods, and thus, provide a framework for judging which method is best suited for the research questions at hand.

The comparison of the polygraphic and the video scorings of sleep-wake states is completed in three phases: 1) a minute-by-minute comparison, 2) a comparison of the summary statistics derived from the two methods, and 3) an analysis of differences in summary statistics between the methods. Other analyses and discussion will describe

systematic discrepancies between the two methods, polygraphic sleep-wake stages during the video's out-of-crib state, and the video method's sensitivity to maturational changes in sleep-wake parameters.

Minute-By-Minute Agreement

Rationale

The most stringent criterion for agreement between methods is minute-by-minute agreement, that is, one method's state coding of each minute of the total recording period is compared to the other's state coding for each simultaneous minute. If there is perfect agreement on the scoring of each minute, then the two methods are equivalent and could be used interchangeably for research questions regarding sleep-wake state proportions and state-to-state transitions. If there is discrepancy between the methods, however, it will be necessary to elucidate its nature and its effect on comparability.

Procedure For Comparison of Polygraphic Stages to Video States

Periods of time when the infant was Out-of-Crib during the laboratory recording night were excluded from these analyses. These periods will be described separately later in this chapter.

To compare the two scoring methods, it was necessary to collapse some of the five or six possible polygraphic ordered stages into ones compatible with the three-state video scoring. The ordered stages (described in Chapter II, Coding of Polygraphic Recordings, page 30 and Appendix IV) were collapsed as follows: at three weeks of age, Indeterminate and Transitional sleep were combined with REM and compared

to Active sleep, and polygraphic Quiet sleep was compared to the video's Quiet sleep. At the older ages, Transitional sleep was combined with REM and compared to Active sleep, and Stages 1, 2, and 3 NREM were collapsed into one NREM stage and compared to Quiet sleep. Figure 3.1 graphically depicts this procedure:

3-Week-Olds

Polygraphic Ordered Stage:	Is Compared To	Video State:
Quiet Sleep	=======>	Quiet Sleep
Indeterminate Sleep Transitional Sleep REM Sleep	=======>	Active Sleep

3- to 6-Month-Olds

Polygraphic Ordered Stage:		Video State:
NREM Stage 1 Stage 2 Stage 3	=======>	Quiet Sleep
Transitional Sleep REM Sleep	=======>	Active Sleep

FIGURE 3.1

Comparison of Polygraphic Stages to Video States

The comparison of periods of wakefulness presented some difficulties that required modification of the ordered stage scoring of the polygraph. The sleep cycling program (described in Appendix IV) which creates the ordered polygraphic stages smoothes brief intrusions of wakefulness less than 10 minutes in duration; the video method scores wakefulness minute-

by-minute. To facilitate comparison, any period of wakefulness of one minute or longer recorded on the polygraph was regarded as an awakening within the ongoing ordered stage.

Analysis

Given the above procedure, a synchronous histogram of the sleep-wake states for the two methods was constructed for each infant, and a contingency table of the minute-by-minute scorings was derived. Figure 3.2 illustrates this procedure:

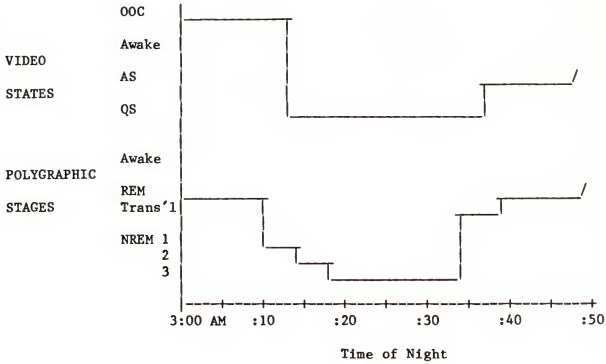


FIGURE 3.2

Sample Histogram of Polygraphic and Video Scorings
(from Infant Ga)

Contingency tables summarizing minute-by-minute scorings for each age group of infants (three weeks, three months, four and one-half months, and six months) can be found in Appendix V.

The minute-by-minute contingency table for each infant was analyzed by the kappa coefficient (k). The kappa is used for measuring nominal (or categorical) scale agreement between two or more judges (Cohen, 1960; Fleiss, 1975). Its advantage over simple percent agreement is that the proportion of agreement expected by chance is subtracted.

By collapsing cells of the contingency table, kappa's may be calculated for each state. For example, to calculate the kappa for agreement between Active sleep and REM, the contingency table would be collapsed into a 2 x 2 table: Active sleep and not-Active sleep by REM and not-REM.

Results

The overall kappa's and kappa's for states for each infant are presented in Table 3.1:

TABLE 3.1

Overall and State Kappa's

Age(wks)	Infant	Overall k	QS/NREM k	AS/REM k	AW/AW k
	Fr	.602	.639	.587	.798
3	Hi	.850	.844	.821	.910
	Jo	.685	.710	.659	.762
	Bi	.654	.608	.536	.877
12	Bu	.743	.748	.734	.796
	Ga	.697	.678	.659	.958
	Bx	.655	.529	.494	.969
18	Es	.730	.751	.636	.838
	Ri	.687	.648	.594	.930
	Wa	.720	.675	.672	.900
	Lu	.336	.270	.226	.782
24	Pi	.633	.611	.584	.850
	Ta	.842	.812	.817	.945
	Median	.687	.675	.636	.877

Landis and Koch (1977) have provided a set of "benchmarks" for describing the relative degree of agreement represented by kappa:

.81 - above = almost perfect
.61 - .80 = substantial
.41 - .60 = moderate
.21 - .40 = fair
.00 - .20 = slight

The group medians for overall agreement and for each state fall in the substantial range. In general, minute-by-minute agreement is fairly good between these two methods of scoring sleep-wake states. Wakefulness is the most reliable state with a median kappa of .877. For all but three infants, agreement for wakefulness falls in the near-perfect range; and even for those three infants, agreement is in the high end of the substantial range.

Agreement for the two sleep states, although respectable, is not as good as for wakefulness. Agreement for Quiet/NREM sleep appears to be slightly better than for Active/REM. Given the high agreement for wakefulness, however, the lower kappa's for the sleep states suggests that therein lies some discrepancy between the polygraph and video scorings. Moreover, it is evident that for some infants (namely, Bi, Bx, and Lu) agreement for the sleep states is, at best, only fair to moderate.

Thus, in terms of minute-by-minute concordance, there is very good agreement between the methods for wakefulness and fairly substantial agreement for the two sleep states. The lower agreement for the sleep states suggests some discrepancy between the two methods in the scoring of Quiet or NREM and Active or REM sleep. It will be important to explore this finding further.

Comparison of Sleep-Wake Statistics

Rationale

The following section assesses the degree of agreement between summary sleep-wake statistics derived from the polygraph and video scorings. Although minute-by-minute agreement was fairly good, less agreement was noted in the scoring of the sleep states, and the question remains whether the summary statistics of sleep-wake states derived by each method are in good agreement, or whether the discrepancy might be reflected in less concordance for some summary statistics.

For this set of analyses, summary statistics of interest in infant sleep research were chosen for comparison. The method for deriving these was described in detail in Chapter II, Description of Sleep-Wake Parameters, page 34.

Analysis

A modification of the intraclass correlation coefficient that is used for assessing reliability was chosen (Kraemer, 1982; Cwik et al., 1982):

$$r_{p.v} = \frac{\sum (p - M)(v - M)}{\sqrt{\sum (p - M)^2 \sum (v - M)^2}}$$

where

p = polygraphic score
v = video score

$$M = \frac{\bar{p} + \bar{v}}{2}$$

d.f. = n - 1

In contrast to the product-moment correlation, this r has the effect of reducing the correlation coefficient when the observed p and v are not identical. Since we are interested in determining precise agreement between methods and not merely the degree of association, the

product-moment correlation is clearly inappropriate. Consider the following example:

TABLE 3.2

Duration of the Longest Sleep Period

(Minutes)

INFANT	Polygraph	Video
A	10	15
B	20	30
C	30	45
D	40	60
Mean =	25.0	37.5

The product-moment r for this hypothetical set of data is 1.00. However, it is evident from the data that for each infant the video scores more minutes of sleep in the longest sleep period than the polygraph. Conversely, the modified intraclass r is 0.65, reflecting the fact that, although the two methods agree to a large extent, there is not perfect reliability. Thus, this modified intraclass r will also impose a stringent criterion for agreement between the two methods.

Results

Table 3.3 summarizes the results of this analysis. For percent awake and the duration of the first Quiet/NREM sleep period, there is very good agreement. There is fairly substantial agreement for total number of awakenings, sleep cycle length and the number of Active/REM sleep onsets. For percent Quiet/NREM and Active/REM, there is moderate reliability. These findings are in accord with the minute-by-minute kappa coefficient: for wakefulness and the summary statistics of

wakefulness, the polygraph and video are close in agreement; while for sleep state proportions, there is slightly less concordance.

TABLE 3.3

Modified Intraclass Correlation Coefficients For Polygraph and Video Scorings

Sleep-Wake Parameter	$r_{p.v}$
Total Number of Awakenings	.712***
Number of Quiet/NREM Sleep Onsets	.148
Number of Active/REM Sleep Onsets	.602**
Percent Quiet/NREM	.569**
Percent Active/REM	.445*
Percent Awake	.944***
Longest Sustained Sleep Period (LSP)	.298
LSP between Awakenings $\geq$ 5 minutes	.913***
Duration of First Quiet/NREM Period	.799***
Sleep Cycle Length	.610**

*** $p \leq .01$
** $p \leq .05$
* $p \leq .10$

For Quiet/NREM sleep onsets and the duration of the longest sleep period, there is positive (though nonsignificant) agreement between methods. With regard to the former, the lack of significant reliability may be due to the small number of Quiet/NREM onsets observed for most of the infants, coupled with the small sample size, and greater disagreement for some infants than others (vid., Appendix VI).

For the longest sleep period, the lack of concordance is due to untimely brief awakenings. As described in Description of Sleep-Wake Parameters, page 34, there is some incompatibility between methods in the coding of wakefulness, which results in more brief awakenings (less than 5 minutes) for the polygraph. For a few infants these brief awakenings distorted the concordance between methods for the longest sleep period.

Consider the following example for infant Bx:

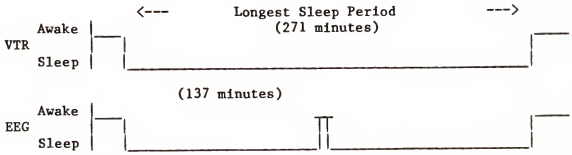


FIGURE 3.3

Effect of Transient Awakenings on Agreement for LSP

About half-way through this infant's longest sleep period, the polygraph coded a brief awakening (2 minutes). Otherwise, both methods agreed there were sustained periods of wakefulness surrounding this long interval of sleep. This may have been a true awakening or may have been merely four consecutive epochs of movement time; either instance may be coded in the same manner on the polygraphic coding forms. In seven of the thirteen infants, such brief awakenings decreased agreement for the longest sleep period by a median of 76 minutes (range: 15 to 263 minutes). If one assesses concordance for the longest interval of sleep between awakenings of 5 minutes or longer, the two methods are in close agreement (intraclass r = .913).

To summarize, there is good concordance between the polygraph and the video method in the scoring of several sleep-wake parameters. For wakefulness, there is especially good agreement for the overall percent of wakefulness and substantial agreement for the number of awakenings within the total recording period. The small divergence between methods in the total number of awakenings centered on brief awakenings and had impact on agreement for the length of the longest sustained period of

sleep. If one redefines this parameter as the period of sleep between sustained awakenings (5 minutes or longer), there is very good concordance between methods.

With regard to other sleep parameters, sleep cycle length, the number of Active/REM sleep onsets and the duration of the first period of Quiet/NREM are fairly similar for both methods. The small sample size and limited number of Quiet/NREM sleep onsets for most of the infants make it difficult to draw any firm conclusions about the concordance between methods for this parameter. There did seem to be greater disagreement for some infants than others. Agreement for sleep state proportions is moderate, with better concordance between Quiet and NREM.

Differences in Sleep-Wake Statistics between Methods

Rationale

Both the minute-by-minute analysis and the comparison of summary statistics suggest some divergence between methods in the scoring of sleep states. This section will examine whether this divergence results in differences in the sleep-wake summary statistics. If there are differences between methods, it will be possible to describe how video recordings of infant sleep might be expected to contrast with comparable polygraphic recordings. The direction of any differences would have important implications for interpreting video-recorded data. If no differences between methods are found, it will suggest that the video yields results similar to polygraphic recording for the sleep-wake parameters which were concordant in the above analyses.

Analysis

The purpose of this analysis is to test the null hypothesis of no differences between methods in summary sleep-wake statistics. The Friedman two-way analysis of variance (X_r^2) will be used.

Results

Table 3.4 summarizes the results.

TABLE 3.4

Differences between Polygraph and Video Scorings

Sleep-Wake Parameter	X_r^2
Total Number of Awakenings	1.23
Number of Quiet/NREM Sleep Onsets	2.77*
Number of Active/REM Sleep Onsets	.08
Percent Quiet/NREM	9.31***
Percent Active/REM	9.31***
Percent Awake	.69
Longest Sustained Sleep Period (LSP)	1.23
LSP between Awakenings $\geq$ 5 minutes	.69
Duration of First Quiet/NREM Period	.08
Sleep Cycle Length	3.77*

*** $p \leq .01$
** $p \leq .05$
* $p \leq .10$

The findings show a significant difference between the polygraph and video in the percents of Quiet/NREM and Active/REM. It is evident from the data (vid., Appendix VI) that the video method tends to score more Active/REM and less Quiet/NREM sleep than the polygraph. There are also slight differences for the number of Quiet/NREM sleep onsets and sleep cycle length: polygraphic scorings will indicate somewhat more Quiet/NREM sleep onsets and shorter sleep cycles than video scorings.

These results, together with the previous analyses, suggest that many sleep-wake parameters (i.e., number of awakenings, percent Awake, duration of the first Quiet/NREM period, longest sleep period between awakenings $\geq$ 5 minutes, and number of Active/REM sleep onsets) are fairly comparable between methods. There may be slight differences in the number of Quiet/NREM onsets and sleep cycle length. Furthermore, the findings confirm a systematic difference in the scoring of the sleep states. The following section will attempt to describe the characteristics of this difference.

Differential Scoring of Quiet/Nrem and Active/Rem States of Sleep

Introduction

From the contingency tables in Appendix V, it is evident that one source of divergence between the methods results from the scoring of Stages 1 and 2 NREM as Active sleep by the video. For the three-month and four-and-one-half-month olds, much of Stage 1 NREM is scored as Active sleep; while for the six-month olds, slightly less than half of the minutes of Stage 1 are still scored as Active sleep. In addition, at all three ages, roughly one-quarter to one-third of Stage 2 NREM is also scored as Active sleep.

From perusal of the infants' sleep-wake histograms (such as depicted in Figure 3.2), it became apparent that the disagreements in scoring tended to occur at particular times. This can best be described graphically:

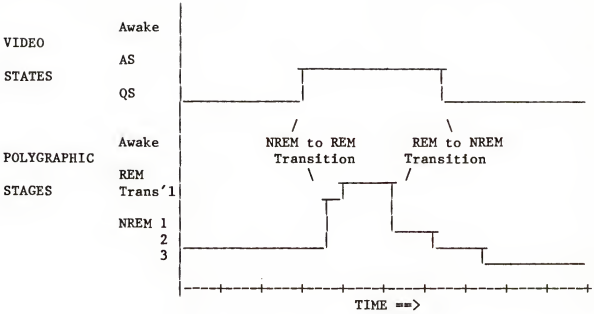


FIGURE 3.4

Scoring Differences at State Transitions

As the diagram suggests, the divergence in scoring between the polygraph and video occurs about the time of transitions between the sleep states. Specifically, both methods agree that a transition from REM to NREM (or vice versa) occurs, but differ on the precise time of the transition. These "transition errors" are often of the sort illustrated above: the video's onset of Active sleep precedes the polygraph's onset of REM sleep and sometimes includes the final minutes of Stage 2 NREM. When there is a transition from REM to NREM, the first minutes of Stage 1 and, sometimes, Stage 2, comprise the final minutes of the interval of Active sleep. Two-thirds to three-quarters of all the minutes of NREM which the video coded as Active sleep consist of transition errors: 76% at three months, 69% at four and one-half months, and 71% at six months.

Of course, some of the minutes of transition error can be attributable to other sources of "error": interrater reliability of each scoring method, measurement error of each method, and time differences

between methods. If these were the only types of error, one would expect an even distribution of errors. Rather, the consistent direction of the transition errors suggests a systematic difference in scoring.

Because of their importance as a source of the divergence between the polygraph and video, the following sections will describe the transition errors in greater detail by the direction of the transition: from NREM to REM and from REM to NREM.

NREM to REM Transitions

The first diagram is a relative cumulative frequency distribution of the instances when the onset of Active sleep preceded the onset of REM. For all three age groups the transition error is less than 10 minutes 85% of the time.

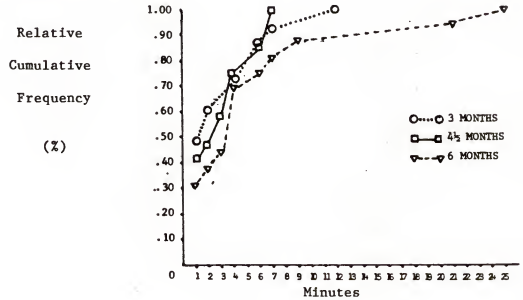
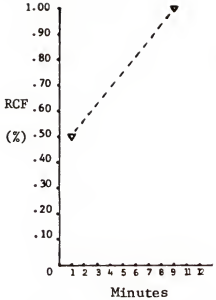


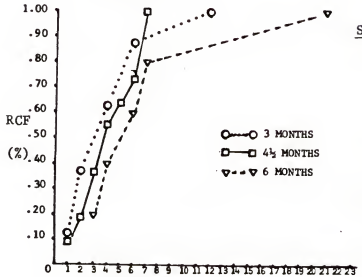
FIGURE 3.5

Minutes before a Polygraphic Transition to REM

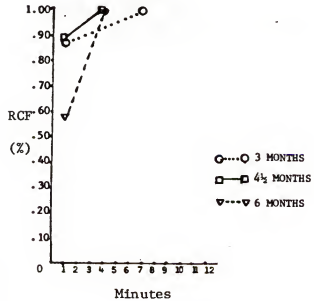
The graphs on the following page show the minutes in error by age and stage of NREM. All of the discrepant minutes of Stage 3 NREM fall



Stage 1 NREM



Stage 2 NREM



Stage 3 NREM

FIGURE 3.6

Minutes before a Polygraphic Transition to REM (by NREM Stage)

within seven minutes, suggesting less transition error when Stage 3 NREM precedes the onset of REM. For the three- and four-and-one-half-month-old infants, none of the minutes in error were Stage 1 NREM; for the six-month olds this comprised 24% of the minutes of transition error. The greatest amount of transition error at all ages was contributed by Stage 2 NREM (74% at 3 months, 82% at 4 1/2 months, 56% at 6 months): when Stage 2 precedes the onset of REM, some portion of it is likely to be scored as Active sleep. The trends for Stages 1 and 2 NREM at six months may be attributable to the emergence of the temporal patterning of sleep within the night: with the gradual shifting of the deeper stages of NREM to the beginning of the night and REM to the latter part of the night, Stage 1 alone, or Stages 1 and 2 may be the only NREM sleep between succesive REM periods.

In contrast, the video rarely misses the onset of REM:

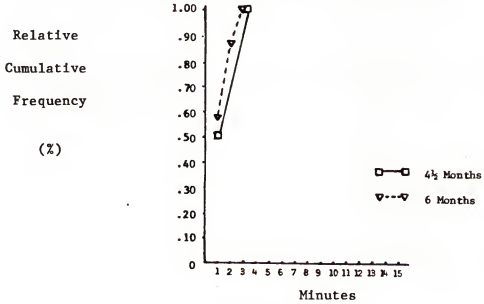


FIGURE 3.7

Minutes after a Polygraphic Transition to REM

In the case of Transitional sleep, there appears to be a change with age. Transitional sleep is somewhat analogous to ascending NREM

in adult sleep: it is usually a brief interval (5 minutes or less) between the end of the deepest stage of NREM achieved in a sleep cycle and the onset of REM. It often consists of Stage 1, but may contain epochs of other NREM stages, wakefulness, movement time and/or REM.

It seemed likely that these intervals would be coded as Active sleep by the video. While this is often the case, there seems to be a gradual trend with age for more of the intervals of Transitional sleep to be coded as Quiet sleep, particularly when the interval is long:

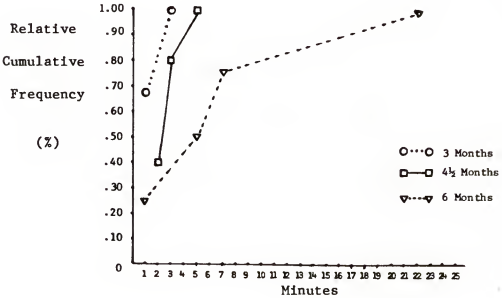


FIGURE 3.8

Minutes after a Polygraphic Transition to Transitional

REM to NREM Transitions

While the transition errors from NREM to REM generally fall within the 10 minute range, those from REM to NREM are longer and confined to Stages 1 and 2 NREM: these are within 15 minutes after the transition to NREM by the polygraph about 85% of the time, and most are Stage 1 NREM (51% at 3

months, 77% at 4 1/2 months, 66% at 6 months). Moreover, there appears to be a gradual retreat toward the polygraph's transition time:

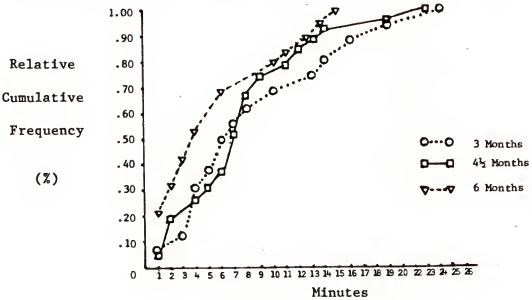


FIGURE 3.9

Minutes after a Polygraphic Transition to NREM

Again, in contrast to the above, the following frequency distribution displays instances in which the video transition to Quiet Sleep preceded a polygraph transition to NREM.

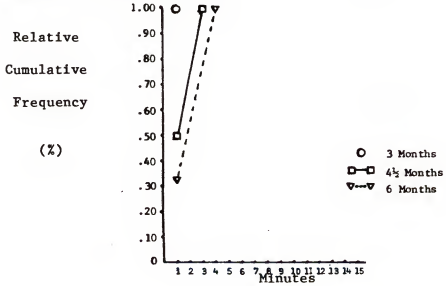


FIGURE 3.10

Minutes before a Polygraphic Transition to NREM

Summary

These graphs reflect interesting trends in the differential scoring of sleep states by the polygraph and video. When a transition is made from NREM to REM, there is less transition error between methods. For these state changes, Stage 2 NREM is most frequently the discrepant state. Whereas in a change from REM to NREM, Stage 1 is the most discrepant. Three developmental changes seem evident: 1) in transitions from NREM to REM, there is a decrease in the amount of transition error for Stage 2 NREM across age from 74% at 3 months and 82% at 4 1/2 months to 56% at 6 months. For the six-month olds, Stage 1 begins to comprise part of the error. This trend may be attributable to the emergence of temporal patterning within the night. 2) There is an increase in the amount of error for Transitional sleep across ages. 3) In transitions from REM to NREM, there is some evidence of a gradual decline in transition error.

Out-of-Crib: The Mystery State

Up to now, the analyses in this chapter have focused on those periods of the laboratory recording night for which there was simultaneous data from both the video and the polygraph. One obvious limitation of the video recording method is that the camera is stationary, focused on the infant's crib. When the child is removed from his crib for soothing, feeding or other caretaking, there is a loss of information about the intervening states. Thus, the night in the laboratory offered a unique opportunity to obtain information from the continuous polygraphic

record about what state or states a child might occupy during his sojourn out of the crib.

The group of thirteen infants spent varying proportions of time Out-Of-Crib during the lab night (vid., Appendix VII). The three-week olds generally spent more time Out-Of-Crib than older infants:

TABLE 3.5

Percent Out-of-Crib
(Median and Range)

Age	
3 weeks	12.6% (11.7 - 18.8)
3 months	1.3% (0.0 - 15.1)
4 1/2 months	2.45% (0.0 - 4.5)
6 months	4.1% (2.8 - 9.8)

For all ages, infants are awake for most of this time: of the total minutes of Out-Of-Crib, 87% are Awake at three weeks, 56% at three months, 100% at four and one-half months, and 94% at six months. The sleep states during Out-Of-Crib are confined to Indeterminate, Stage 1 NREM and REM: 4% Indeterminate and 9% REM at three weeks, 22% Stage 1 and 22% REM at three months, and 1% Stage 1 and 5% REM at six months.

In addition, the longer the duration of the Out-Of-Crib interval, the more likely it is to contain sleep:

TABLE 3.6

Sleep during Out-of-Crib

Duration of Out-of-Crib (Minutes)	Frequency	Frequency with Sleep	Minutes of Sleep (Median and Range)
1 — 10	15	1	1.0
11 — 20	15	2	3.0 (2 - 4)
21 — 30	2	1	5.0
> 31	4	4	17.5 (12-24)

In general, a mother tends to return her infant to the crib once her soothing or caretaking is complete, or the child falls asleep. For all

the intervals over 30 minutes, these mothers seemed inclined to allow the infant to sleep for awhile before returning the child to bed. In two of these, each infant had a brief period of sleep followed by another wakeful period, then a final return to sleep and, after a time, the infant was returned to the crib. Though the sample of infants is small, these findings suggest interesting differences in maternal caretaking style and, possibly, maternal-infant interaction. Most mothers tend to return the infant to the crib awake or shortly after a return to sleep, while a few mothers tend to delay returning the child to bed until well asleep.

Age-Related Changes in Sleep-Wake Parameters

Given the differences in precise agreement that have been described, how sensitive is the video to age-related changes in sleep-wake parameters? Developmental changes are the focus of many infant sleep studies, and therefore, any useful technique should be able to distinguish age-related changes in sleep-wake patterning. This section will compare the sensitivity of the polygraph and video to developmental changes in sleep.

Analysis

The statistical test of choice is the Spearman rank correlation coefficient, a nonparametric measure of the degree of association. It is appropriate for reasons of both small sample size and assumptions underlying the distribution characteristics of the variables. The

sleep-wake parameters were the same ones compared in an earlier section of this chapter, Comparison of Summary Sleep-Wake Statistics.

Results

Table 3.7 summarizes the results of the Spearman analyses. For all the sleep-wake parameters measured, similar developmental trends are evident for both methods. The number of Quiet/NREM sleep onsets

TABLE 3.7

Spearman Correlations of Sleep-Wake Parameters With Age

Sleep-Wake Parameter	Polygraph	Video
Total Number of Awakenings	.201	.219
Number of Quiet/NREM Onsets	.473*	.562**
Number of Active/REM Onsets	-.242	.060
Percent Quiet/NREM	.510**	.337
Percent Active/REM	-.516**	-.582**
Percent Awake	-.088	.014
Longest Sleep Period	.152	-.008
First Quiet/NREM Period	.653**	.658**

** $p \leq .05$
* $p \leq .10$

and the duration of the first Quiet/NREM period of sleep increase with age, while the proportion of Active/REM sleep decreases with age. However, the polygraph indicates an increase with age in the proportion of NREM sleep; the video also indicates a positive relationship between age and percent Quiet sleep, although it does not quite reach significance. Thus, for the usual summary statistics of infant sleep, the video is sensitive to similar developmental changes as the polygraph, although it tends to underestimate the increase in Quiet sleep.

Summary of Findings

Sleep-Wake States and Summary Parameters

Using stringent criteria, there is generally good agreement between the polygraph and video minute-by-minute codings of sleep-wake states, and for many of the summary descriptors of the night's sleep. There is especially good agreement in the scoring of the percent of wakefulness and the duration of the first period of Quiet/NREM sleep; substantial agreement for total awakenings, the number of Active/REM sleep onsets, and sleep cycle length; moderate agreement for the percent of Quiet/NREM and the percent of Active/REM sleep.

The two summary parameters for which there is no concordance are the number of Quiet/NREM sleep onsets and the duration of the longest sleep period. The small sample size and low frequency of observing a Quiet/NREM sleep onset make it difficult to assess agreement statistically on this parameter. To some extent, the lack of concordance may be due to slightly different numbers of awakenings for each method. If one examines the actual data (vid., Appendix VI), there is general agreement for the presence or absence of a Quiet/NREM onset and the overall frequency for all but three of the infants (Bi, Bx, and Wa). It is noteworthy that agreement is not dependent on the destination NREM stage: all observed NREM sleep onsets were to Stage 1. In sum, this limited sample makes it difficult to draw a firm conclusion on the concordance for Quiet/NREM sleep onsets. There may be individual differences in sleep onset that influence concordance on this parameter: while there is consensus between methods for many infants, for a few infants there is not.

Comparability between methods for the longest sustained sleep period is substantially affected by the coding of brief awakenings. As previously described, the polygraphic coding of wakefulness coincides with the coding of movement time: the assumption is that periods of movement time in excess of 30 seconds constitute wakefulness. Given that motility is a component of REM sleep, the convention of coding consecutive epochs of movement time as wakefulness tends to present a picture of the night's sleep as rather more disrupted than is evident behaviorally. The sleep cycling program (Nagel, et al., 1982; Appendix IV) attempts to circumvent this problem by smoothing intrusions of wakefulness of ten minutes or less, which results in the opposite problem: a picture of the night's sleep as more composed than is warranted. There are, of course, instances in which the video codes transient wakefulness that coincide with the polygraph's. A solution adopted by many infant laboratories is to include behavioral notes on the polygraphic recording during epochs of movement time to better differentiate transient awakenings from within-sleep motility. Sustained periods of movement time do tend to correspond closely with behavioral wakefulness: thus, agreement for the duration of the longest period of sleep between longer awakenings (5 minutes or more) is very good.

The less-than-perfect concordance in the scoring of sleep states is of some concern. Tests for differences between methods reveal a systematic discrepancy in scoring: the video method scores more Active/REM and less Quiet/NREM sleep than the polygraph. Slight differences are also found for the number of Quiet/NREM sleep onsets and sleep cycle length.

Differential Scoring of Quiet/NREM and Active/REM States

The systematic discrepancy between methods in the scoring of sleep states is described as "transition error." Specifically, transition error is the inclination of the video method to begin a period of Active sleep before the polygraph's transition to REM sleep, and to end an interval of Active sleep after the polygraph's transition to NREM sleep. This is the primary source of divergence between the methods in the scoring of sleep states. Transition error is somewhat longer when the state change is from REM to NREM: 15 minutes vs. 10 minutes for a transition from NREM to REM. There seem to be some developmental trends in transition error: the amount of error for Stage 2 NREM decreases, the amount of error for Transitional sleep increases, and there is evidence of a gradual decline in transition error for transitions from REM to NREM.

Out-Of-Crib

The laboratory recording night provides interesting information about the video's Out-Of-Crib state. Infants of all ages are awake for most of the time they spend Out-Of-Crib. When the Out-Of-Crib interval exceeds 30 minutes, it is more likely to contain sleep, although the sleep is confined to the lighter stages, namely, REM, Indeterminate, and Stage 1 NREM. While there is generally only a small proportion of sleep during Out-of-Crib, it might present a problem for research questions involving sleep onsets. There is also some evidence of varying maternal caretaking styles: most mothers tend to return the child to bed once caretaking is complete or just after the child falls

asleep. A couple of mothers, however, were inclined to return the infant to the crib after the child had been asleep for some time.

Age-Related Changes in Sleep-Wake States

The video method is sensitive to developmental changes in the same sleep-wake parameters as the polygraph: the increase in the number of Quiet/NREM sleep onsets, decrease in the proportion of Active/REM sleep, and increase in the duration of the first Quiet/NREM period of sleep. The one difference between methods is that the polygraph is also sensitive to increases in the proportion of Quiet/NREM sleep, while for the video this did not quite reach significance.

Discussion

Polygrahic and Video Concordance

The analyses in this chapter indicate a good degree of correspondence between the polygraph and video in the scoring of sleep-wake states and the summary statistics of sleep. There are, however, important differences. Given a set of video sleep-wake recordings, one would expect less Quiet/NREM and more Active/REM than the comparable set of polygraphic recordings would indicate. There would be very good to moderate agreement for other variables, except Quiet/NREM sleep onsets. Given the small sample size, low frequency of Quiet/NREM onsets and, possibly, individual differences, the findings are inconclusive about agreement between methods on this parameter. If the research questions involved developmental changes in sleep-wake patterns, the findings would be similar to those of polygraphic recordings, although changes in the proportion of Quiet/NREM sleep may be slightly underestimated.

The findings are in accord with the Anders and Sostek (1976) study. In both studies, there is high agreement for wakefulness. While their two-week olds showed better agreement for Active/REM sleep, the three-week olds in the present study evidenced better agreement for Quiet/NREM (vid., kappa's for state). However, the smaller sample of the present study may have a bearing on this difference. For their older age group (8 weeks), there was better agreement for Quiet/NREM, and the present study confirms this, despite a different polygraphic scoring system for the older infants. It also confirms that good concordance between methods is obtained by the scoring of states rather than behavioral categories, as in the Fuller et al. (1978) study.

With regard to the Fuller et al. study, there was also some evidence in the present study for individual variability in agreement, especially for sleep state proportions and Quiet/NREM sleep onsets. The infants for whom there was the largest divergence between methods in sleep state proportions included Bi, Bx and Lu; and for Quiet/NREM sleep onsets, infants Bi, Bx and Wa. The question arises whether some clinical factor might account for this. On the infant status interview, it was noted that Lu had a mild upper respiratory infection at the time of recording. The polygraph summary notes also indicated some immaturity in NREM sleep, in that few good spindles were evident. In this regard, it is noteworthy that his proportion of Stage 3 NREM is small in comparison to the other two six-month-olds: 9% vs. 30% for Pi and 24% for Ta. Infant Bx also had a mild URI, otitis and was febrile during the polygraphic recording night. His mother reported that, though he typically slept through the night, he had sometimes awakened

since the onset of the illnesses. Bi, though in good health, was one of two infants whose mother did not stay overnight during the laboratory recording, and thus was cared for by the polygraphic technician. For infant Wa, the infant status interview reported he was still slightly congested from an URI two weeks prior to the recording.

While there is some evidence that an environmental (i.e., maternal absence in an unfamiliar setting) or biologic stressor, or immaturity of the EEG could influence the concordance between methods, this interpretation is offered with reservations. First, the sample size is small. Second, there were other infants who one might suggest were subject to an environmental or biologic stress. Infant Ri's mother was also absent during the laboratory recording night. Infants Pi and Ta were teething, and infant Ga had a mild facial rash. Thus, if a biologic or environmental stress can impact on concordance, it must vary across infants.

Differential Scoring of Quiet/NREM and Acive/REM Sleep

There are two uses for the analyses describing a differential scoring of Quiet/NREM and Active/REM. First, one might recommend changes to the video scoring method that could increase its correspondence with the polygraph. Secondly, one can derive a simple set of formulae to apply to video scored states to obtain an equivalent of the polygraphic scoring.

With regard to the first, the video scores Active Sleep as long as phasic events and movements occur every five minutes. For transitions from REM to NREM, the video scoring could disregard the final two or

three movements and end the REM period with the last movement after which no REMs are seen; or, in instances when REMs are not discernible, the Active sleep period could end at the point when movements occur only as frequently as every five minutes. For transitions from NREM to REM, in which the video is in closer agreement with the time of the polygraphic change, the video scoring could begin a REM period with the first movement just prior to the first REMs or phasic twitches.

The second strategy is appropriate for approximating polygraphic NREM and REM proportions for a set of scored video data. The following formulae can be applied to video data to determine the polygraphic equivalent for NREM (including Transitional):

AGE	
3 Months	Video QS minutes x 1.46 = NREM minutes
4 1/2 Months	Video QS minutes x 1.42 = NREM minutes
6 Months	Video QS minutes x 1.40 = NREM minutes

The polygraphic equivalent for REM can be approximated by subtracting the difference between the NREM and QS minutes from the minutes of Active Sleep. This assumes that the infants in this study were a representative sample, of course. For the infants with less transition error, this procedure will overestimate the proportion of Quiet/NREM sleep. As a group, however, the sleep state proportions will be closer to the polygraph's. The trend of the formulae suggests a gradual decrease in transition error, such that at an older age the polygraph and the video might correspond closely.

From a different perspective, the pattern of transition errors offers evidence of a developmental change in motility during Quiet and Active sleep in the early months of life. Motility during Quiet sleep

seems to diminish first; the trends in transition error suggest a gradual decrease in motility during Stages 1 and 2 NREM, and Transitional sleep. The diminution in motility during Active sleep proceeds more slowly: in young infants there is almost continuous activity (e.g., large and small body movements, phasic twitching of the fingers, smiles, grimaces, and sucking, in addition to rapid eye movements), while in older infants motility is frequent though discontinuous. The decline of near continuous activity in Active sleep may parallel the disappearance of undifferentiated REM states about 3 months of age.

The developmental course of motility's association to EEG stage is not well documented. Movements during sleep in older children are known to be less frequent, but the relationship to sleep stage and the time course of decrease has not been studied. An early paper by Dement and Kleitman (1957) reported more gross body movements before and after REM periods and few movements during delta sleep in adults. The recent time-lapse study by Aaronson et al. (1982) found that 83% of all postural shifts tended to occur at the times of transitions between states (i.e., wake-to-NREM, NREM-to-REM, REM-to-NREM).

In some respects, Aaronson and others' results are not directly applicable to the present study. The time-lapse recording speed differs (1 frame per minute vs. 3 frames per second in the present study) which affects the types of activity that can be observed: shifts in respiratory rate and variability, rapid eye movements, and facial expressions are clearly discernible in the faster recording mode. In the present study distinctions are not made between types of body movements. During the first six months of life, many infants are not capable of the major postural shifts Aaronson et al. describe.

However, the similarities between the studies are compelling. Aaronson and others' results suggest a much closer link between motility and sleep stage exists in adults: 60% of all postural shifts occurred within 1 minute of a transition from NREM to REM, or vice versa. Based on their findings and animal studies, they proposed that a bimodal motor control system suppresses motility during REM and NREM, and that movement tends to occur during the change from one control system to the other.

If these assertions are correct, the present study indicates that these motor control mechanisms are less developed in young infants. The small transition error for Stage 3 NREM suggests that the mechanism responsible for the suppression of motility during NREM develops earlier in delta sleep, and gradually in lighter stages of NREM (i.e., Stages 1, 2 and Transitional). Moreover, mechanisms which inhibit motility during REM sleep also develop gradually: large and small body movements are typical of Active sleep in these young infants.

The trends toward decreasing transition error suggests that maturation of these control mechanisms parallels, though follows, EEG maturation. This might also account for the poorer concordance evident in the Fuller et al. video study: one would expect poorer development of motor inhibitory controls in premature infants.

Thus, the video technique may be sensitive to developmental changes in motility that are reflective of neurological maturation. While the changes to the scoring system suggested above would increase correspondence with the polygraph, it may impair the technique's sensitivity to certain apsects of neurological maturation, ones to which the polygraph is not

sensitive. One would recommend modifications to the scoring only if the research questions demand close correspondence to the polygraph.

Based on its own merits, the video technique may be a useful, unobtrusive screening method for young infants in whom neurological defect or immaturity is suspected. This possibility is an area for future study.

CHAPTER IV

NIGHT-TO-NIGHT STABILITY IN SLEEP-WAKE PATTERNS

Introduction

This chapter describes the night-to-night stability of sleep-wake patterns in five to six month old infants. The analyses focus on the three consecutive nights of home video recording for the sample of fifteen infants described previously (vid., Chapter I, Purpose and Description, page 5, and Chapter II, Subject Selection, page 32). The primary purpose of this chapter is to provide a frame of reference for the next chapter, which will compare sleep-wake patterns at home with those in the laboratory. The analyses will also be of interest to researchers studying the establishment of regularity in sleep-wake states in infancy.

The assessment of stability is completed in two phases: 1) a comparison of the degree of concordance between the consecutive nights of sleep, and 2) an analysis of the differences between nights. Other sections will describe the "ecology" of sleep in the home with reference to dyadic and individual sleep-related behaviors of the mother and infant.

The chapter begins with a brief discussion of stability in sleep and the issues involved in describing it.

Stability in Sleep

What does it mean to have stable sleep? Given a set of consecutive nights, how does one decide whether the sleep is stable? Of the difficult questions to address, the first questions to consider are: what is "stability," how does it apply to sleep, and how can it be measured or described?

The essence of stability is that repeated observations of a variable yield unvarying or minimally varying results. The limits one chooses for "unvarying or minimally varying" can be presumptive, if one has prior knowledge of the variable in question, or empirical, in the absence of prior knowledge, as is the case in the present study.

In reference to sleep or any other phenomenon of interest, a description of stability is linked necessarily to the set of parameters studied. Sleep can be described in many different ways: by its rhythmic aspects, which may include circadian (i.e., onset/offset time within the 24-hour day, or its relationship with other physiologic measures such as body temperature or hormonal secretions), ultradian (i.e., REM-NREM cycles), or seasonal rhythms; as a set of behavioral states, common in infancy studies, or polygraphic stages, and the summary of these states/stages or their components (i.e., state/stage percentages, REM density, onset latencies of the states/stages, wakefulness after sleep onset, total sleep time, etc); by the presence of disorders or abnormalities, such as narcolepsy, hypersomnia, night terrors, nightwaking, apnea, or the insomnias. The parameters in the present study include sleep-wake state proportions, indices of sleep maturation, and circadian and ultradian rhythms.

It is conceivable that some parameters may be stable, while others are not. To illustrate this issue, and further describe the data in the present study, consider the following hypothetical sleep patterns:

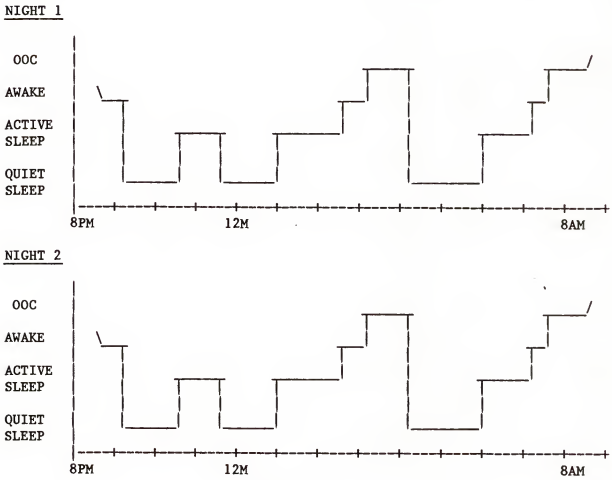


FIGURE 4.1

Sleep-Wake Histograms for Child A

These two nights are identical in every respect: the child goes to sleep at the same time each night, wakes at the same time each morning and in the interim has identical amounts of Quiet sleep, Active sleep, Wakefulness and Out-of-Crib. There is no argument that this child's sleep is stable from one night to the next. Suppose, however, another child (child B) went to bed at 6 PM on the first night and 2 AM on the

second night, but the pattern of sleep was otherwise identical to child A's. Would one consider child B's sleep stable?

Now, consider the sleep patterns of child C:

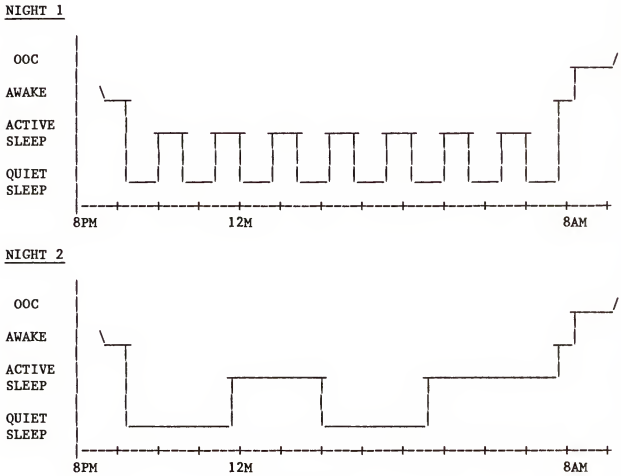


FIGURE 4.2

Sleep-Wake Histograms for Child C

This child goes to bed and wakes at the same times each day and has identical amounts of both Quiet and Active sleep. However, on the first night the Quiet-Active sleep cycles are short, while on the second night they are long. Would one consider this child's sleep to be stable? Is it more stable than child B's?

Thus, consecutive nights of sleep can be stable on some sleep measures, but not on others. One could say that child A's sleep is stable in every respect, both in diurnal regularity and internal (within sleep) regularity. Child B's sleep also shows internal stability, but the diurnal placement of sleep varies greatly from night to night; while child C's sleep is stable in its diurnal placement and in some internal aspects (i.e., state percentages, but not sleep cycle length).

Ways of Describing or Measuring Stability

So far, the concept of stability has been described by simply taking the child's sleep-wake histograms for consecutive nights, lining them up, and looking for any discrepancies. If there are none, one can conclude that the sleep from one night to the next is absolutely stable. One might call this "strict" stability -- perfect agreement between observations. The sleep-wake histograms of child A are an example; not only are the histograms identical but any statistics derived from the nights' sleep are also in perfect agreement.

This way of describing stability is the ideal that comes to mind when one thinks about stability. But what if the child's sleep-wake patterns do not meet the criteria for strict stability, such as child B or C? Are there any other ways of assessing or describing stability? Typically, the studies of stability in sleep have described it in other ways. One way might be termed "group" stability. Consider the following example:

TABLE 4.1

Percent of Wakefulness

INFANT	Night 1	Night 2	Night 3
A	0	100	50
B	100	0	50
C	50	100	0
D	50	0	100
MEAN	50	50	50

On the average, this group of infants spent 50% of the time awake each night. The amount of wakefulness from one night to the next was identical and there were no differences between group means or variance across observations. The limitation of this way of describing stability is evident: it gives a very good idea of the average amount of a parameter from one observation to the next, but little information about the amount of the parameter for an individual infant. In the example, each of the individual infants was awake 50% of the time on only one of the three nights, while on the other nights each was awake as little as 0% or as much as 100%. In other words, as a group the amount of wakefulness was very stable from one night to the next, but for individual infants no night-to-night stability is evident.

The other common way of describing stability is by the relationship between variables across observations. One might call this "structural or organizational" stability: the relationship between two or more parameters is the same from one observation to the next. This is determined by a correlation coefficient. As an example, consider the study by Snow et al. (1980) reported in Chapter I. This study reported a positive correlation between the frequency of wakeful distress and

the frequency of sleep-wake transitions at 6, 9 and 18 months of age, and concluded that during this period of development there is a stable relationship between these two variables. The limitation here is similar to that of group stability: unless the relationship between the two parameters is perfect (a perfect positive or negative correlation), knowledge of the parameters for an individual infant is somewhat uncertain. Given the knowledge of one parameter and the correlation coefficient, one can clearly make a good guess at the level of the other parameter. For some infants, the guess will be quite accurate, but for others it will not. Moreover, one cannot know whether the parameters for an individual remain at a similar level from one observation to the next. Even in the case of a perfect correlation, this may be so. Suppose in the above study there was a perfect positive correlation between wakeful distress and sleep-wake transitions at each age. Given knowledge of wakeful distress, one could determine precisely the number of sleep-wake transitions for any infant. However, one could not predict across observations. Knowledge of an infant's wakeful distress at 6 months might give no information about the child at either of the other two ages.

Another way of describing stability might be termed "individual" stability. The focus is on the degree to which an individual is consistent across observations relative to the rest of the group. Stability is also determined by a correlation coefficient, in this instance applied to the observations. Suppose we have a set of five observations for each of three infants, A, B and C:

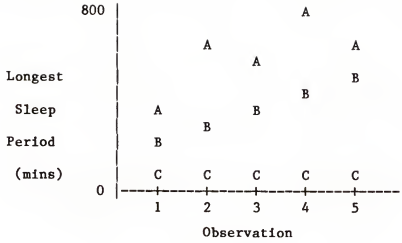


FIGURE 4.3

Individual Stability

For this sample of infants, the individuals are consistent across the five observations: infant A always obtains the highest score; B, the median score; and C, the lowest score. Each individual maintains his position relative to the rest of the group across observations. The limitation of this method is obvious. Although each infant may be consistent relative to the rest of the group, the level of the parameter may vary across observations. In the example, infant A's longest sleep period fluctuates, but appears to be increasing across the observations; infant B displays a pattern of gradual, systematic increases; while infant C's longest sleep period is exactly the same for all observations.

To summarize, there are several different ways of describing stability. When one says a child's sleep is stable from one night to the next, the ideal that comes to mind is that of strict stability. Since this ideal is probably never encountered in the real world, one must rely upon other methods of measuring stability. However, each one has limitations and pitfalls that must be kept in mind in interpreting findings. The best approach may be to combine methods so that a more comprehensive picture or description of the actual data is given.

Stability of Sleep-Wake Parameters across Nights

Rationale

As previously stated, the purpose of measuring the stability of sleep-wake states in this sample of infants is to provide a frame of reference for the chapter which will compare sleep at home with sleep in the laboratory. If there is stability in some or all of the parameters, it will be possible to describe the effect of sleeping in the laboratory upon these. For any that are not stable, one will not be able to state confidently whether they are affected by sleeping in the laboratory.

For this set of analyses, the sleep-wake parameters chosen for comparison are those that characterize a night's sleep for an infant, and might be sensitive to environmental disruption: the summary sleep-wake state proportions, total awakenings and total sleep time, the semi-Markov indices of maturation (TPI and HTI), and measures of circadian and ultradian rhythmicity (Bedtime, Risetime, LSP, the minutes of LSP in 12-5 AM, and sleep cycle length). The methods for deriving these is described in detail in Chapter II, Description of Sleep-Wake Parameters, page 36.

Analysis

For the analysis of this data, an intraclass correlation coefficient (r_1) was selected. Since the purpose of this analysis is to assess the degree to which a particular parameter is consistent for an individual across the three nights (i.e., individual stability), this statistic is particularly well-suited: whereas the product-moment correlation and the Spearman rank correlation can be used to measure

reliability between two variables or observations, the intraclass r expresses the reliability of individual ratings for two or more observations (Ebel, 1951). Because it is not likely that the data of the present study meet the assumptions of normality required for use of this statistic, ranked data replaced the raw data in the calculations. This procedure results in a statistic which is equivalent to the average internal rank correlation (Kraemer and Korner, 1976).

Results

Table 4.2 on the following page summarizes the results of this analysis. The data for each variable across the three nights can be found in Appendix VIII.

The findings indicate considerable night-to-night stability in many sleep-wake parameters. With regard to the sleep states, Active sleep shows stability, while Quiet sleep does not. The Holding Time Index, which reflects maturity in the temporal patterning of Quiet and Active sleep within the night, also shows stability.

The variables which reflect disruption of sleep, total awakenings and the proportions of Awake and Out-of-Crib, are also stable. The percent Out-of-Crib is a dyadic, caretaking variable. It most often reflects times when the baby awakens, calls to mother and is removed from his crib for a time for caretaking. A mother will rarely remove her sleeping infant. Stability in this parameter suggests that a mother spends a consistent amount of time each night intervening with her wakeful infant. Total awakenings show somewhat better stability than percent Awake, suggesting that infants awaken a consistent number of

times each night, but are slightly less consistent in the amount of time spent awake. However, the percent Out-of-Crib may be a confounding variable: part of the time the baby is awake may occur during Out-of-Crib.

TABLE 4.2

Night-to-Night Consistency in Sleep-Wake Patterns

Sleep-Wake Parameter	r_1
Percent Quiet Sleep	-.017
Percent Active Sleep	.286*
Percent Awake	.276*
Percent Out-of-Crib	.520***
Total Number of Awakenings	.647***
Total Sleep Time (TST)	.601***
Bedtime	.744***
Risetime	.575***
Longest Sustained Sleep Period (LSP)	.708***
Minutes of LSP in 12-5 AM (%)	.323*
Sleep Cycle Length	-.181
Transition Probability Index (TPI)	.620***
Holding Time Index (HTI)	.264*

* $F^{14,28}_{.05} \geq 2.06$

** $F^{14,28}_{.01} \geq 2.80$

*** $F^{14,28}_{.005} \geq 3.25$

Parameters which reflect the integrity and duration of sleep, total sleep time, the longest sleep period and the Transition Probability Index, are also very stable. Thus, the amount of sleep, the duration of the longest uninterrupted episode of sleep and the pattern of state-to-state transitions during the night are stable and characteristic for an infant.

The parameters which reflect the circadian regularity of the period of sleep (Bedtime, Risetime, and minutes of the LSP in 12-5AM) are also quite stable for infants. By five to six months of age, infants establish stable patterns of going to bed and awakening in the morning, and in the proportion of the longest sleep period which falls between the hours of midnight and 5 AM.

Differences in Sleep-Wake Parameters between Nights

Rationale

As described in the discussion on the measurement of stability, one difficulty in assessing stability across observations (i.e., individual stability) is that one cannot be certain whether there are systematic changes occurring across the observations. Systematic differences between nights would have important implications for the study of infant sleep: one may not be able to assess adequately the level of a parameter by one observation. Furthermore, the direction of the differences may have implications for the use of the video recording method. Systematic differences between the first and subsequent nights would suggest that video recording, even in the home, results in a first night effect.

Analysis

The purpose of this analysis is to test the null hypothesis of no differences between nights in the sleep-wake parameters. The statistic of

choice is the Friedman two-way analysis of variance (X_r^2), which is appropriate for multiple observations in related samples (Siegel, 1956).

Results

Table 4.3 summarizes the results of this analysis:

Table 4.3

Differences between Nights in Sleep-Wake Parameters

Sleep-Wake Parameter	X_r^2
Percent Quiet Sleep	2.13
Percent Active Sleep	.13
Percent Awake	3.33
Percent Out-of-Crib	.63
Total Number of Awakenings	2.43
Total Sleep Time (TST)	.53
Bedtime	.63
Risetime	1.30
Longest Sustained Sleep Period (LSP)	.53
Minutes of LSP in 12-5 AM (%)	.23
Sleep Cycle Length	1.73
Transition Probability Index (TPI)	.10
Holding Time Index (HTI)	1.20

* $p \leq .10$
** $p \leq .02$
*** $p \leq .01$

There were no significant differences between nights in any of the sleep-wake parameters. Thus, the level of a parameter does not vary systematically from one night to another. These findings suggest that video recording in the home does not result in a "first night" effect.

Ecology of Sleep in the Home

Introduction

The above analyses suggest that there is substantial night-to-night consistency in sleep-wake patterns in five to six month old infants, and that the video recording technique seems to be a nonobtrusive method for studying sleep in the home. In themselves, these findings are important recommendations for the technique. A wealth of other information about sleep-related behavior is also available. In particular, the video technique offers the opportunity to study aspects of nighttime maternal caretaking[1] and infant behavior. The stability in the proportion of Out-of-Crib offers some evidence of consistency in maternal caretaking during the night. There are many aspects of nighttime maternal caretaking and infant behavior that could be measured. The following section describes three that will be considered in the present study.

Description of Dyadic and Individual Sleep-Related Parameters

Maternal interventions during infant sleep

During the night, a mother sometimes comes into her infant's room to check while the child is asleep (Anders, 1979). She may simply come to the side of the crib and look briefly, or she might cover, gently

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[1] In sections which describe the ecology of sleep and dyadic parameters, caretaking behaviors have been ascribed to mothers. In the present sample, all nighttime interventions were made by mothers. For purposes of clarity, pronouns and possessive pronouns will be male in gender when referring to the infant and female in gender when referring to the caretaker.

touch or reposition her baby. These "sleep interventions" are infrequent, usually occurring only once or twice during the night, yet are observed in many mother-infant pairs.

Intervention-to-sleep latency

Sometimes an infant will awaken during the night and cry. When a mother answers her child's cries, there are many things she might do. She might simply soothe the child, give him a pacifier or bottle, or take the baby from the crib for feeding or other caretaking. Her intervention may be very brief and simple, or may include an array of different or repeated caretaking behaviors. Given that a mother's interventions with her child can be single and brief or very complex, one measurable aspect is the time required for an infant to return to sleep following mother's intervention, i.e., the intervention-to-sleep latency. This is defined as the time in minutes from the mother's first intervention with her wakeful infant until the child returns to sleep (i.e., has at least 20 minutes of sustained sleep or a complete sleep cycle).

Both mother and infant contribute to this parameter. For the child's part, it may include aspects of his temperament, soothability, developmental stage, and his state at the time of awakening, that is, how aroused, fearful, sleepy or hungry he might be. For the mother, it may include her caretaking style and repertoire, with this infant and with other children, her interpretation of the child's awakening, and perhaps her state at the time of awakening. It is necessarily a complex dyadic variable, whose components can vary from one mother-infant pair to another and perhaps from one occasion to another.

Awakenings without maternal intervention

Occasionally, an infant will awaken at night without crying (Anders, 1979; Paret, 1983). In the past it was assumed that an infant who did not cry out was asleep the entire night. These awakenings are usually brief. The child may play for a time with toys in the crib, or may snuggle up with a blanket or pacifier and quickly return to sleep.

Comparison of Dyadic and Individual Parameters

The purpose of this section is to describe the characteristics of these parameters in this group of infants. Since the sample is very small and the occurrence of these parameters varies across nights and infants, conventional statistical analyses are not applicable. Rather, a purely descriptive approach will be taken with the intent of stimulating the reader to the possibilities inherent in the study of sleep-related behaviors.

Intervention-to-sleep latency

Intervention-to-sleep latencies are observed for many of the infants in the study. Most of the latencies comprise the night-waking infants and infants who have not settled. Although roughly equal numbers are observed on each of the nights (25 on night 1, 23 on night 2, and 24 on night 3), there are different numbers of latencies for different infants each night. For example, one infant awakened and cried for mother once on the first night, four times on second night, and twice on the third. Thus, strict comparisons between nights are compromised.

The following graph is a relative cumulative frequency distribution of the duration of all intervention-to-sleep latencies by night:

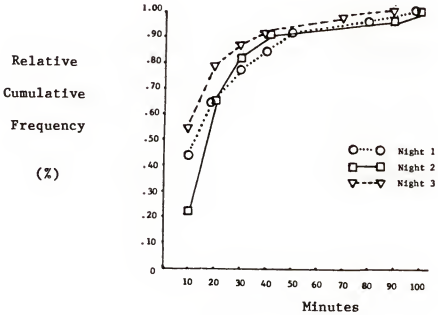

FIGURE 4.4

Minutes from First Maternal Intervention to Return to Sleep

There is remarkable consistency across nights in how readily the infants return to sleep. Most resumed sleep within 20 minutes of mother's intervention. On each of the nights, only two infants required more than one hour to fall asleep. The median intervention-to-sleep latency is 13 minutes for night 1 (Range: 1 to 100 minutes), 16 minutes for night 2 (Range: 1 to 91 minutes), and 10 minutes for night 3 (Range: 1 to 90 minutes). The graph should be interpreted as reflecting trends for the whole group rather than for individual infants. For example, the infants with the longer than one hour latencies are two different infants each night.

Maternal interventions during sleep

Roughly half of the mothers checked on their sleeping infants at least once during each of the nights of recording. Most frequently, a mother checks on her sleeping baby once during the night. Each night two mothers checked at least twice (up to four times); however, only one of these was the same mother all three nights.

TABLE 4.4

Maternal Interventions during Sleep

Total of Maternal Sleep Interventions	Frequency of Infants Night 1	Night 2	Night 3
0	8	7	7
1	5	6	6
$\geq$ 2	2	2	2

A mother tends to check on her sleeping infant at one of three times: early in the evening, a few minutes up to one or two hours after the child's bedtime; late in the evening, about 10:30 PM to 12:30 AM, presumably prior to her retiring; and in the morning, after 7:00 AM, in anticipation of, or perhaps to stimulate, her child's awakening. The early evening and late evening sleep interventions are most frequent.

There does appear to be some consistency in this maternal behavior and its timing: eleven of the fifteen mothers made sleep interventions on at least one of the three recording nights. Nine of these made sleep interventions on two nights, and three mothers, on all three nights. Moreover, seven of the nine mothers intervene in the same time period, i.e., early or late evening or in the morning.

Of special interest is the relationship observed between maternal sleep interventions and the infant's sleep history:

TABLE 4.5

Maternal Sleep Interventions and Infant Sleep History

Sleep History	Frequency of Infants Night 1	Night 2	Night 3
Not Settled (N=4)	0	0	1
Night-waking (N=6)	3	4	5
Sleeping (N=5)	4	4	2

All of the "sleeping" infants (i.e., those who had settled and were not night-waking at the time of study) and five of the six night-waking infants received a sleep intervention on at least one of the nights, while only one of the infants who had not settled received a sleep intervention.

Awakenings without maternal intervention

Transient awakenings in which the infant does not cry for mother are observed on each of the nights of recording, although sporadically: these occur in eight infants on the first night, one infant on the second night and five infants on the third night. The likelihood of occurrence does not seem to be related to the infant's sleep history: four of the five sleeping infants, three of the six night-waking infants, and all of the infants who had not settled have at least one such awakening. However, their duration and the time of night in which they occur does differ:

TABLE 4.6

Infant Sleep History and Nighttime Wakefulness

Sleep History	Duration of Awakening in Minutes (Median and Range)	Time of Night
Not Settled	4.5 (1 - 21)	After 5 AM
Night-waking	3.0 (1 - 10)	11:30 PM - 5 AM
Sleeping	15.0 (1 - 46)	After 4:30 AM (6 of 7)

For the sleeping infants and those who had not settled, silent awakenings tend to occur toward the end of the night's sleep, while for night-waking infants they tend to occur in the middle of the night. The duration of the awakenings is quite brief for the night-wakers and unsettled infants, but tends to be longer for the sleepers.

In comparing silent awakenings to ones during which the infant cries for mother, there are interesting differences between the groups. Across the three nights of recording, the probability of a sleeping infant calling to mother during an awakening is .30, and each of these occurred before 10:30 PM or after 5:30 AM. Not surprisingly, the probability of a night-waking or an unsettled infant calling for mother during an awakening is much higher (.88 and .79, respectively) and not related to time of night.

Summary of Findings

Sleep-Wake Parameters

The findings in this chapter indicate that many sleep-wake parameters are stable for five- to six-month-old infants. Parameters which reflect the integrity, maturity and duration of the night's sleep (i.e., total sleep time, longest sleep period, and the semi-Markov sleep indices) and those which reflect its diurnal regularity (i.e., Bedtime, Risetime, and the minutes of the LSP in 12-5AM) are consistent across nights. Variables reflecting the disruption of sleep, including total awakenings, percent Awake, and percent Out-of-Crib, are likewise stable.

With regard to sleep state proportions, only Active sleep showed stability across nights.

With regard to differences in sleep-wake patterns between the nights, no significant differences were found for any of the parameters.

Ecology of Sleep at Home

The home video recordings provided an opportunity to describe sleep-related behaviors in this sample of infants. An infant usually returns to sleep readily (within 20 minutes) following mother's intervention, although on some nights the child may require an hour or more to resume sleep. Slightly over half of the mothers check on their sleeping infants regularly during the night, and this behavior occurred more frequently for the night-waking and sleeping infants. Many infants display brief awakenings during the night in which they do not cry out, though these are shorter for unsettled and night-waking infants than for sleeping infants. While awakenings during the night are less frequent for sleeping infants than for night-waking and unsettled infants, the sleeping infants are less likely to cry for mother during an awakening.

Discussion

Sleep-Wake Parameters

The findings in this chapter confirm previous studies of sleep stability in infants. With regard to sleep pattern history, the proportions of infants who had settled, who were night-waking, and who

had not settled were similar to those described in the Moore and Ucko study (1957). Jacklin et al. (1980), in a study of sleep pattern development using parent diaries which were completed twice about one week apart, found moderate stability in the longest period of sleep per day at six months of age. In the present study, the LSP evidenced even better stability when measured from one night to the next.

The findings also confirm, to some degree, the studies describing stability in aspects of state organization. While none of the parameters in the present study directly measures "within state" characteristics, the semi-Markov sleep indices, which reflect the direction of state-to-state transitions and temporal patterning of sleep, were stable. With regard to the HTI, Anders et al. (1983) report that this variable correlates with the proportion of Quiet sleep. Thus, since it is stable, the HTI may be a better measure of the maturity of sleep than the traditional proportion of Quiet sleep.

With regard to studies of stability in older children and adults, the infants in this study display similar proportions of the sleep states across nights, although only the percent Active sleep was consistent across nights for individuals. Interestingly, total sleep time, percent Awake and percent Active sleep, which are analogous to parameters in the Clausen et al. (1974) study, were also consistent for infants. This suggests that, regardless of a subject's age, these aspects of sleep are stable and characteristic for an individual.

Stability in sleep-wake patterns does not appear to be related to the child's sleep history. At the time of study, roughly two-thirds of the infants had either not settled or were night-waking. One might expect that these infants would not be consistent from night-to-night.

Although they could be described as "immature" in the ability to sustain a long period of uninterrupted sleep, their sleep is clearly stable in many respects. Stability in Bedtime and Risetime indicates a regularity in the timing of the sleep period. Moreover, the other parameters of sleep and wakefulness are also consistent, though perhaps not in the direction an infant's parents might prefer. Since these infants are developmentally normal, this suggests that sleep-wake stability is a fundamental property of an intact CNS which emerges fairly early in life. The determinants of late settling or night-waking appear to be distinct from those which govern stability in sleep and wakefulness.

The finding of no systematic night-to-night differences seems to indicate that the video recording method does not result in a "first night" effect in young infants. None of the mothers expressed concerns that the presence of the equipment had disrupted or altered the child's usual pattern. However, given the heterogenity of the sample, it is possible that some differences between nights might be obscured. This could be tested by consecutive recordings of a more homogeneous group.

Ecology of Sleep at Home

A unique advantage of the video technique is the opportunity to investigate nighttime maternal caretaking and infant behavior. The findings offer some evidence of consistency in these parameters. Across the three nights, there was individual stability in the proportion of Out-of-Crib, suggesting that mothers spend a consistent amount of time caring for a wakeful infant. The similar patterns of intervention-to-sleep latencies suggest that infants at this age tend to return to sleep within a circumscribed period of time, although an individual infant

may vary from one night to the other, or one awakening to another, in how quickly sleep is resumed.

Awakenings during which the infant does not cry out seem to vary across nights, and are generally shorter for the night-waking and unsettled infants than for "sleeping" infants. Sleeping infants were also less likely to call for mother during an awakening. When they did, it was either in the evening or early morning, rather than in the middle of the night. When night-waking and unsettled infants wakened, they usually called to mother, regardless of the time of night. These findings suggest that the sleeping infants are better able to return to sleep on their own and, perhaps, are sensitive to environmental "time cues."

With regard to interventions during sleep, mothers seem to be fairly consistent in their checking, both from one night to another and in the time of night they check. However, sleep interventions were made almost entirely by mothers of night-waking infants and sleeping infants. Only one of the mothers with an unsettled infant checked on any of the nights. One possible explanation may be that mothers of unsettled infants do not check for fear of disturbing the child's sleep. If so, one would expect that mothers of night-waking infants would also not intervene during sleep. Perhaps these interventions provide a subtle cue of mother's presence. For an unsettled infant, awakenings during the night may serve the purpose of reassuring the child of mother's availability, in the absence of the cues. While for infants who are night-waking, these interventions may disturb the continuity of the night and result in later awakening. Though speculative, there is some support for this notion. As reported earlier, Carey (1974) found that

night-waking infants have a low sensory threshhold to environmental stimulation, and thus, interventions during sleep may cause subtle disruption which results in night-waking.

The video technique may provide insights into nighttime infant and caretaker behaviors that affect sleep. Settling and night-waking are important concerns for both parents and infant care specialists. However, there is little reseach at present that can address these concerns. The association of nighttime caretaking activities to other aspects of the dyadic relationship, and their impact on sleep-wake states and the development of diurnal entrainment are exciting possibilities for future study.

CHAPTER V

SLEEP-WAKE PATTERNS AT HOME AND IN THE LABORATORY

Introduction

This chapter will compare the sleep-wake patterns at home with those in the laboratory in the thirteen infants who were studied in both settings (described in Chapter 1, Description and Purpose, page 5, and Chapter II, Subject Selection, page 25). The intent of these comparisons is to assess what impact sleeping in the laboratory has on the composition of sleep-wake states in young infants, and in what ways the laboratory night's sleep resembles the home night's sleep. The data will consist of the time-lapse video recordings in each setting.

Since the purpose is both to compare and to contrast sleep in the two settings, the analysis will comprise two phases: 1) a measurement of the degree of concordance in sleep-wake parameters between the home and laboratory, and 2) a test of the null hypothesis of no differences in sleep between the settings. A similar protocol was followed in the previous chapter on night-to-night stability. The findings of both chapters will be compared. Other sections will describe the ecology of sleep in the home and laboratory.

Stability of Sleep-Wake Parameters across Settings

Rationale

The infants in the present study were recorded on two consecutive nights, the first night at home and the following night in the laboratory. While the previous chapter found good night-to-night stability in many sleep-wake parameters at home, the question remains whether a change in setting might alter sleep. The analyses in this section will describe the ways in which sleep-wake patterns at home correspond to those in the laboratory.

The sleep-wake parameters to be compared are the same ones measured in the stability chapter, and were described in detail in Chapter II, Description of Sleep-Wake Parameters, page 36.

Analysis

The purpose of this analysis, as in the previous chapter, is to assess the degree to which a particular parameter is consistent for an individual infant across nights (i.e., individual stability). In this case, the two nights of sleep occur in different settings. The method of analysis, the intraclass correlation coefficient (r_1) applied to ranked data, is the same.

Results

Table 5.1 on the following page summarizes the results of these analyses. Three parameters show stability across settings: the proportion of Active sleep, Risetime and the Transition Probability

Index. Risetime reflects an aspect of diurnal regularity, namely the offset time of the sleep period. The Transition Probability Index reflects the maturity of state-to-state transitions. These were also consistent across nights in the previous chapter, and thus may be descriptors of sleep-wake patterns in young infants that are impervious to environmental disruption.

TABLE 5.1

Stability of Sleep-Wake Parameters across Settings

Sleep-Wake Parameter	r_1
Percent Quiet Sleep	.159
Percent Active Sleep	.540*
Percent Awake	.264
Percent Out-of-Crib	.315
Total Number of Awakenings	.142
Total Sleep Time (TST)	.286
Longest Sustained Sleep Period (LSP)	.308
Bedtime	.091
Risetime	.543*
Minutes of LSP in 12-5 AM (%)	-.138
Sleep Cycle Length	.055
Transition Probability Index (TPI)	.499*
Holding Time Index (HTI)	.066

* $F^{12,12}_{.05} \geq 2.69$

** $F^{12,12}_{.01} \geq 4.16$

Differences in Sleep-Wake Parameters between Settings

Rationale

The purpose of these analyses is to test the null hypothesis of no differences in sleep-wake patterns between the home and laboratory. The

finding of few stable parameters between settings raises the question of whether the night in the laboratory might in some way affect the pattern of sleep and wakefulness. If there are differences between nights, then it will be possible to describe what effect the laboratory night has on sleep. If no differences are found, it will suggest that sleep in the laboratory does not differ systematically from sleep at home.

Analysis

As in the previous chapter, the Friedman two-way analysis of variance (X_r^2) was chosen for these analyses. The sleep-wake parameters are the same as in the above comparisons.

Results

Table 5.2 summarizes the results.

TABLE 5.2

Differences in Sleep-Wake Parameters between Settings

Sleep-Wake Parameter	X_r^2
Percent Quiet Sleep	.69
Percent Active Sleep	1.88
Percent Awake	6.19**
Percent Out-of-Crib	1.19
Total Number of Awakenings	6.23**
Total Sleep Time (TST)	.04
Longest Sustained Sleep Period (LSP)	9.20***
Bedtime	1.88
Risetime	.04
Minutes of LSP in 12-5 AM (%)	3.73*
Sleep Cycle Length	.08
Transition Probability Index (TPI)	9.30***
Holding Time Index (HTI)	1.19

* $p < .10$
** $p < .02$
*** $p < .01$

There are five parameters which differ between the settings: the total number and proportion of wakefulness, the Transition Probability Index, the Longest Sleep Period, and the minutes of the LSP between 12-5 AM. The number of awakenings and the proportion of wakefulness are greater during the laboratory recording night. The maturity of state-to-state transitions, as reflected by the Transition Probability Index, is diminished. Thus, contrary to the previous analysis, the TPI is not stable across nights. The duration of the Longest Sleep Period is curtailed and, to some extent, the minutes of the LSP during 12-5 AM. The data for these analyses can be found in Appendix VII.

The Ecology of Sleep at Home and in the Laboratory

Introduction

Implicitly, the experience of sleeping in a laboratory differs from sleeping at home. The hospital room in which the laboratory recordings took place was comfortable and quiet. But, for an infant, it differed from home in many ways: the ambient sights, sounds and lighting, unfamiliar faces, an unfamiliar bed, the sensation of the attached electrodes and nasal thermistor. Mother's presence probably tempered the experience for most infants. Nonetheless, infants seemed to adapt differentially to the recording procedures. Some tolerated the laboratory night well, while others slept fitfully. The two infants (Bi, Ri) whose mothers were not present during the night were each different in adaptation: Ri had a long uninterrupted period of sleep early in the night, followed by a long awakening in the middle of the

night; Bi had difficulty initially settling to sleep, and later awakened briefly a number of times.

The previous chapter found overall (i.e., group) consistency in some aspects of nighttime dyadic and individual sleep-related behaviors, namely the intervention-to-sleep latency and sleep interventions. This section will describe these parameters in the present sample of infants, comparing the occurrence at home with the lab.

Intervention-to-Sleep Latencies

Intervention-to-sleep latencies are observed for ten of the thirteen mother-infant pairs on the home night, and for all infants on the lab night (n.b.: the data for the two infants whose mothers were not present are excluded from the lab night descriptions). Again, there are different numbers of latencies for different infants on each of the two nights. A total of 17 were observed on the home night, and 30 on the lab night.

The infants differ in how readily they return to sleep following mother's intervention in the two settings. At home, more than half of the infants are asleep within 20 minutes, while in the lab roughly half have not resumed sleep after 40 minutes. The median intervention-to-sleep latency is 19 minutes at home (Range: 1 to 244 minutes[1]), and 40 minutes in the lab (Range: 1 to 142 minutes). The shape of the curve for the home night resembles those in the stability chapter. The greater proportion of

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[1]One mother (Ta) reported she herself had fallen asleep while nursing her baby, and thus the child did not return to the crib for some time.

longer latencies may be reflective of the wider age range in the present sample.

The following plot, similar to the one in the previous chapter, displays the durations of intervention-to-sleep latencies for the home and lab nights:

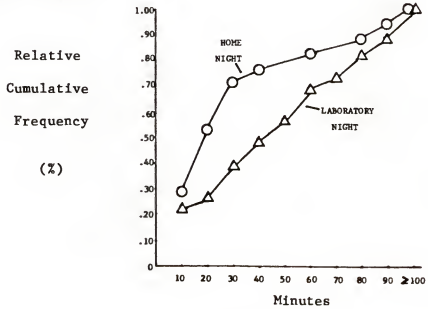


FIGURE 5.1

Minutes from First Maternal Intervention to Return to Sleep

Maternal Interventions during Infant Sleep

Just over half of the mothers checked on their sleeping infants during the home night of recording. Four mothers made a sleep intervention once, two mothers intervened twice, and one mother, three times. Again, this corresponds closely with the maternal sleep interventions of the stability chapter.

Sleep interventions during the laboratory recording night differed somewhat in frequency and character. In addition to maternal sleep

interventions, the polygraphic technician also made interventions during sleep. In some instances, these were "maternal," such as covering or repositioning the infant, or gently moving the cord of electrodes off the baby's face. More commonly, the technician might try to adjust or gently reapply a loose electrode or thermistor. The following table summarizes sleep interventions:

TABLE 5.3

Sleep Interventions at Home and in the Laboratory

Total Sleep Interventions	Frequency of Infants				
	Home	Laboratory			
		Mother	Tech-"M"	Tech	Total
0	6	4	8	2	0
1	4	1	1	1	0
$\geq$ 2	3	6	2	8	11

For the mothers, there did seem to be some degree of consistency across settings: four of the seven mothers who intervened during sleep at home also intervened in the lab, though more frequently (3 to 12 times); two of the mothers who did not intervene at home also did not intervene in the lab. However, as the total indicates, all of the infants received more than two sleep interventions, of one sort or another, on the lab night (Range: 3 to 17). Thus, for the infant during both sleep and wakefulness, the experience of laboratory recording is quite unusual.

Summary of Findings

Sleep-Wake Parameters

The analyses indicate consistency between the home and laboratory in the proportion of Active sleep and Risetime. The differences in

sleep-wake patterns between settings were reflected in the total number of awakenings and proportion of wakefulness, the longest sleep period, the TPI, and, to some degree, the minutes of the LSP in 12-5 AM.

Ecology of Sleep at Home and in the Laboratory

There were both consistencies and difference between the settings in maternal caretaking behaviors. Some mothers who intervened with a sleeping infant at home also did so in the laboratory, though more frequently. In addition, infants in the laboratory received interventions during sleep from the polygraphic technician, both "maternal" interventions and those directed toward the recording equipment. Intervention-to-sleep latencies during the home recording are similar to those observed in the stability chapter, though slightly longer. During the laboratory recording night, these were generally much longer.

Discussion

Sleep-Wake Parameters

The findings in this chapter indicate that sleeping in the laboratory setting results in a clear "first night" effect in young infants. This is manifested by an increased number of awakenings, an increased proportion of wakefulness, a curtailing of the longest sustained period of sleep and, to some extent, its diurnal timing, and a decrease in the maturity of state-to-state transitions (TPI). The amount of wakefulness observed in the lab setting is roughly double that

observed during the home night's sleep, while the LSP is on the average two hours shorter than at home.

These results differ markedly from the adult study by Coates et al. (1979), which reported strong correlations between sleep-wake parameters at home and in the laboratory. However, the findings generally confirm previous studies of the effects of laboratory recording on sleep in infants. Bernstein et al. (1973) reported increased wakefulness and shorter morning nap periods in four-month olds during sham polygraphic recordings in the laboratory. In a longitudinal study during the first year of life, Emde and Walker (1976) reported briefer morning naps during polygraphic recording after one month of age. For two- and eight-week-old infants, Sostek and Anders (1975) reported that laboratory recording disrupted diurnal variations in waking activity, though there appeared to be adaptation during the course of recording.

The present study indicates that laboratory recording causes some disruption in the diurnal regularity of sleep. Bedtime was not consistent across settings, and the shorter LSP in the laboratory resulted in a somewhat reduced proportion during the hours of 12-5 AM. However, Risetime (i.e., the offset time of the sleep period) was stable across settings.

For sleep state proportions and total sleep time, no significant differences were observed between the nights. The proportion of Quiet sleep was not stable in the study of night-to-night stability, nor did it vary across settings, suggesting that variation in Quiet sleep proportions is characteristic in infants. While other studies have reported differences in aspects of NREM sleep during laboratory recording, it appears that the overall proportion of Quiet sleep is not

systematically affected. The Holding Time Index, total sleep time and percent Active sleep were stable from night-to-night. However, only Active sleep was stable across settings. This finding is contrary to the first night effect in adults, who typically show a reduction in REM. Perhaps the adaptation period is sufficient for this sleep parameter but not others. The results seem to suggest that on the laboratory night there is a disruption in the amount of sleep (TST) and in the temporal patterning of sleep within the night (HTI) that is not uniform across infants. Some infants sleep more in the lab than at home, and some display a more mature temporal patterning in the lab than at home. The reported differences in NREM sleep during laboratory recording may be a reflection of disruptions in the infrastructure of sleep, to which the HTI is sensitive.

The pattern of state-to-state transitions, measured by the Transition Probability Index, is systematically affected by the laboratory recording. Since this variable is consistent for individuals, this suggests that the decrease in the TPI is uniform across infants. Infants who display an immature pattern of transitions at home appear even more immature in the laboratory, while infants with a mature pattern of transitions at home are somewhat less mature in the lab. Thus, the TPI seems to reflect an intrinsic characteristic of a child's sleep-wake pattern that is systematically affected by environmental disruptions.

In sum, the results suggest that laboratory recordings of sleep and wakefulness in young infants correspond to home night's sleep only in the proportion of Active sleep and the time of the morning awakening. It appears that the opportunity for the infant to adapt to the laboratory

setting through instrumentation earlier in the day does not permit enough time for complete adaptation to occur.

Ecology of Sleep at Home and in the Laboratory

Maternal caretaking in the laboratory also differs. Mothers were more likely to intervene with a sleeping infant, and intervened more frequently than at home. This may support the previously suggested view that sleep interventions act as a cue of mother's presence. However, they may also have contributed to the increased wakefulness observed. Another possibility is that the interventions resulted merely from increased proximity to the infant during sleep. All but two of the infants slept in their own bedrooms at home, while during the lab night the mothers slept in the recording room. There was some consistency in sleep interventions across settings: four of seven mothers who intervened at home also intervened in the lab; two mothers who did not intervene at home also did not intervene in the lab.

The dyadic intervention-to-sleep latency also differed during the lab night. The trend of latencies during the home night of sleep was similar to those in the stability study. The somewhat longer median latency may be due to the greater age range in the present sample. On the lab night, more and longer latencies were observed, suggesting that the infants were less "soothable" than at home. Once awake, infants generally required a longer time to return to sleep than at home. The percent Out-of-Crib, which was stable across home nights but not across settings, also suggest differing patterns of caretaking during the laboratory night.

To summarize, the findings suggest that the laboratory night's sleep corresponds to home sleep in some respects, but that there are important differences in sleep-wake parameters and in patterns of maternal caretaking and infant responsiveness.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary of Findings

The purpose of the present study was threefold: to assess the concordance of polygraphic and video recordings of sleep-wake states in infants up to six months of age; to examine the influence of the laboratory on infant sleep-wake patterns; and to assess night-to-night stability in young infants. This section will summarize and discuss the results.

In comparing minute-by-minute scorings of the polygraph and video, there is near-perfect agreement in the two methods for wakefulness, and fairly substantial agreement for Quiet/NREM and Active/REM sleep. When summary statistics derived from each method are compared, there is very good to moderate agreement for all parameters except Quiet/NREM sleep onsets. Given the small sample size, low frequency of observing a Quiet/NREM sleep onset and, possibly, some individual differences, it is difficult to draw a firm conclusion about agreement between methods on this variable. However, an analysis of differences between methods revealed a systematic discrepancy in the scoring of sleep states. Given a set of video recordings of sleep-wake states, one would expect less

Quiet/NREM and more Active/REM sleep than the comparable set of polygraphic recordings. Other parameters would be fairly similar.

The discrepancy in the scoring of the sleep states was accounted for by "transition error." This is the inclination of the video to begin a period of Active sleep before the polygraph's transition to REM sleep, and to end an interval of Active sleep after the polygraph's transition to NREM sleep. Formulae were presented which correct for this divergence. The trend of the formulae suggested a gradual decrease with age in transition error, so that at an older age polygraphic and video scorings of sleep states may correspond more closely. It was proposed that the decline in transition errors may reflect the maturation of motor control mechanisms that parallel, though follow, EEG maturation. The video method's use of motility and phasic activity in the scoring of sleep states may be more sensitive to aspects of neurological maturation in motor control mechanisms than the polygraph and, thus, have utility as an unobtrusive screening tool.

The laboratory recording night was an opportunity to investigate the video's Out-of-Crib state. Infants of all ages were awake for most of the time spent Out-of-Crib. When the interval exceeded 30 minutes, it was more likely to contain some light sleep (i.e., REM, Indeterminate, or Stage 1 NREM).

The video method is sensitive to maturational changes in the same sleep-wake parameters as the polygraph: the increase in Quiet/NREM sleep onsets, the decrease in the proportion of Active/REM sleep, and the increase in the duration of the first interval of Quiet/NREM sleep. For the proportion of Quiet/NREM sleep, there was a positive correlation with age for the video, though it did not quite reach significance.

For research questions involving developmental changes in sleep-wake patterns, the results would be similar for both methods, although changes in the proportion of Quiet/NREM sleep might be slightly underestimated by the video.

In the sample of fifteen five- to six-month-old infants who were studied for three consecutive nights at home, there was considerable night-to-night stability in sleep-wake patterns. Parameters which reflect the integrity, maturity and duration of sleep (i.e., total sleep time, longest sleep period, Transition Probability Index, Holding Time Index), the diurnal regularity of the sleep period (i.e., Bedtime, Risetime, minutes of the LSP in 12-5 AM), and the disruption of sleep (i.e., total awakenings, percent Awake, percent Out-of-Crib) were all stable from one night to the next. For the sleep state proportions, only Active sleep was stable. Thus, in normal infants, stability in nighttime sleep-wake patterns emerges by five months of age, and is not related to whether or not the child has settled. There were no significant differences between nights in any of the parameters, suggesting that video recording in the home does not result in a "first night effect" in young infants.

Home recordings permit the description of aspects of nighttime maternal caretaking and infant behavior. Although there is some variability from one night to another, infants generally return to sleep within 20 minutes following a maternal intervention. The small sample size precludes conclusions about the origins of late settling or night-waking, though there were some subtle differences between the groups in maternal and infant behavior. Many infants wake briefly during the night without signalling for mother. Such awakenings were

generally shorter for the night-waking infants and those who had not settled than for "sleeping" infants (i.e., infants who had settled and were not night-waking at the time of study).

"Sleeping" infants were also less likely to call for mother during an awakening. When they did, it was either in the evening or early morning, rather than in the middle of the night. When night-waking and unsettled infants wakened, they usually called to mother, regardless of the time of night. These findings suggest that the sleeping infants are better able to return to sleep on their own and, perhaps, are sensitive to environmental "time cues."

Sleep interventions were made mostly by mothers of night-waking infants and sleeping infants. Although both night-waking and unsettled infants do not sleep through the night, it may be that the origin of waking differs for each group. For the unsettled infant, waking may serve the purpose of reassurance. For the night-waking infant, the mother's interventions during sleep may disrupt the continuity of sleep and result in later wakening.

A sample of thirteen infants, three weeks to six months in age, were studied at home and in the laboratory. Sleeping in the laboratory resulted in a "first night effect," characterized by an increased number of awakenings, a greater percent of wakefulness, decreased maturity in state-to-state transitions, and a curtailing of the longest sleep period and disruption of its diurnal timing. The only parameters that were stable across settings were the percent of Active sleep and Risetime.

These findings are in accord with previous infant studies, which have reported increased wakefulness and shortened sleep periods during laboratory recording. The present findings also suggest some disruption

in the diurnal regularity of the night's sleep. With regard to total sleep time and sleep state proportions, the effects of the laboratory vary. The percent of Quiet sleep was not stable in the study of night-to-night stability, nor did it systematically vary across settings. The Holding Time Index, total sleep time, and percent Active sleep were stable from night-to-night. However, only percent Active sleep was stable across settings. This suggests that on the laboratory night there is a disruption in the amount of sleep (TST) and in the temporal patterning of sleep within the night (HTI) that is not uniform across infants: some infants sleep more in the lab than at home, and some infants display a more mature temporal patterning in the lab than at home. Laboratory recording does not seem to disrupt Active sleep, perhaps because the adaptation period is sufficient for this sleep parameter but not others.

Differences were also observed in maternal caretaking during the laboratory recording night. Mothers were more likely to intervene with a sleeping infant, and to intervene more frequently than at home. The percent Out-of-Crib, which was stable across home recording nights but not across settings, also indicates differential maternal caretaking in the lab. When awake, infants generally took a longer time to resume sleep in the lab, suggesting that they were less easy to soothe than at home.

Conclusions

The past two decades of infant sleep research have been productive in describing the ontogeny of sleep and wakefulness during the first

year of life. As research proceeds from the description of normative patterns and individual differences to the assessment of clinical disorders and evaluation of potential treatment methods, the use of methods that permit long-term, reliable monitoring can be of great advantage. Recent technical developments permit unobtrusive monitoring and assessment in many areas of behavioral research and medicine. To ensure the comparability of new research information, any new technical aid must be evaluated against the "standards" of the field, in terms of its limitations and advantages.

The present study demonstrates that time-lapse video recording as a technique for studying infant sleep-wake patterns compares favorably with polygraphic recordings, though the two methods do not yield identical results. If its sensitivity to developmental changes in motility can be confirmed through future research, it may have utility as a screening tool for infants with suspected neurological immaturities.

Clearly, the polygraph cannot be replaced in assessing neurological maturation, such as the presence of spindles or delta activity. However, the present study indicates that laboratory recording disrupts the integrity and maturity of infant sleep patterns. The video method permits the study of sleep in the natural setting, without a first night effect. Time-lapse recording at home would also be useful for evaluating common concerns of parents, such as late-settling and night-waking, and to yield information on which to base treatment recommendations. For example, the present study described subtle differences in maternal caretaking and infant behavior in unsettled and night-waking infants compared to "good sleepers." Carey's studies suggest temperament and

breast-feeding are related to night-waking. Perhaps differences in temperament, feeding and nighttime mother-infant behavior interact to result in late settling or night-waking. Polygraphic recordings in the laboratory cannot address these issues.

Finally, time-lapse video recording could complement the polygraph in the study of clinical sleep disturbances. Abnormal movements and behavior are associated with many sleep disorders, such as somnambulism, night terrors, sleep apnea, and restless legs syndrome. As an adjunct, video recording would permit a complete description of the polygraphic and behavioral events associated with such episodes. Home recordings could also be useful in the evaluation and treatment of disorders (e.g., the insomnias) for which polygraphic evaluation is usually considered too obtrusive or expensive.

As a technique, time-lapse recording has many potential applications in the study of both normal sleep development and pathology. Sleep is thought to be an important dimension in understanding mechanisms which underlie wakeful functioning. Time-lapse video recording may permit the study of aspects of sleep that will clarify our understanding of these mechanisms and, perhaps, the functions of sleep.

APPENDIX I

INFANT STATUS FORM

STATUS FORM

NAME_____ Date of Recording_____

Age_____ Experimenter_____

(Describe)

	Past week	Today
Sleeping		
Eating		
Illnesses		
Injuries		
Baby sitters		
New environments		
Stresses		
Developmental achievements		

MORNING AFTER

Note comments about recording period

APPENDIX II

SAMPLE VIDEO CODING FORM FOR INFANT BU AND TRANSITION PROBABILITY AND HOLDING TIME MATRICES BY PHASES OF NIGHT

SUBJECT NAME (Bov)

DATE 8.10.80

2 CODER T.O.

TIME STARTED 21:13

BABY 3 mos ♀

prone
Ø Self-soothe prop

SLEEP

Maternal Interventions:

1	21:13-2	21	5:50-2	41		61	23:28-34-checks
2	21:21-1	22	6:35-1	42		62	
3	22:06-2	23	6:53-2	43		63	
4	22:18-1	24	7:02-3	44		64	
5	22:53-2	25	7:18-2	45		65	
6	23:23-1	26	7:24-3	46		66	
7	23:34-4	27	7:36-4	47		67	
8	0:03-3	28	X	48		68	
9	0:07-2	29		49		69	
10	0:29-1	30		50		70	
11	1:03-2	31		51		71	
12	1:30-1	32		52		72	
13	1:54-2	33		53		73	
14	2:23-1	34		54		74	
15	2:32-2	35		55		75	
16	3:23-1	36		56		76	
17	3:40-2	37		57		77	
18	4:17-1	38		58		78	
19	4:34-2	39		59		79	
20	5:30-1	40		60		80	

Time of Night

Hour : Minute -- State →

Sleep
1 QS
2 AS
3 AW
4 Out of Crib

Transition Probability and Holding Time Matrices
by Phases of Night
for infant Bou

P_{ij} = the probability of making a transition from state i to state j.

$h_{ij}(T)$ = holding time density function given the infant is in state i and will make the next transition to state j; mean holding time.

Phase 1

	QS	AS	AW	OOC
QS	P_{ij} / $h_{ij}(T)$	.67 / 40.0		.33 / 11.0
AS	1.00 / 18.0			
AW		1.00 / 4.0		
OOC			1.00 / 29.0	

Full Night

	QS	AS	AW	OOC
QS		.90 / 24.3		.10 / 11.0
AS	.83 / 31.7		.17 / 7.5	
AW		.67 / 10.0		.33 / 12.0
OOC			1.00 / 29.0	

Phase 2

	QS	AS	AW	OOC
QS		1.0 / 22.3		
AS	1.0 / 35.7			
AW				
OOC				

Phase 3

	QS	AS	AW	OOC
QS		1.0 / 18.0		
AS	.60 / 46.0		.40 / 7.5	
AW		.50 / 16.0		.50 / 12.0
OOC				

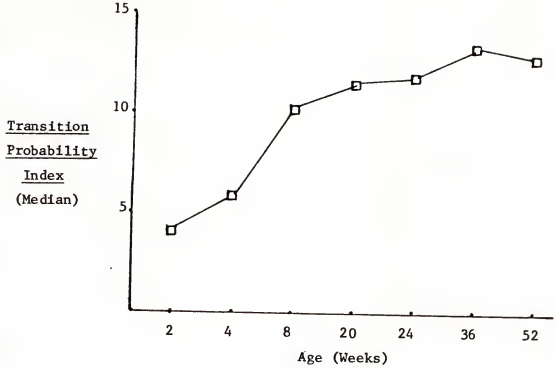
Transition Probability Index = 14.0

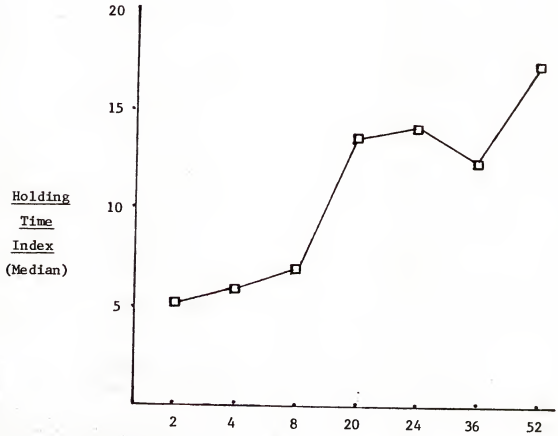
Holding Time Index = 16.3

Infant awakens rarely, has long QS to AS holding times in phase 1.

APPENDIX III

PLOTS OF MEDIAN TPI AND HTI





(Source: Anders et al., 1983)

APPENDIX IV

SLEEP CYCLING PROGRAM

Sleep Cycling Program

(from Nagel et al., in preparation, 1982)

I. Criteria for REM Onset

A. There is less than one minute of wake (two consecutive 30-second epochs) in the first five minutes following a wake period

AND

B. There are at least one-and-a-half consecutive minutes of REM in the ten minutes following a wake period

AND

C. The one-and-one-half minutes of REM are not preceded by stages 3 or 4.

II. Criteria for Beginning First Sleep Cycle of a Sleep Period

A. There is any stage 3 or 4 in the first five minutes following a wake period

AND

B. There are not two consecutive epochs of wake

AND

C. The criteria for REM onset are not met.

III. Criteria for Ending One cycle and Beginning the Next

A. If the ordered stage (J) is 3-4, and the scored sleep stage for the epoch in consideration (N_1) is 1, and neither a wake period, nor one minute of REM occurs within 25 minutes

OR

B. If the ordered stage (J) is REM (5) and the scored sleep stage for the epoch in consideration (N_1) is 3 or 4

OR

C. If the ordered stage (J) is REM (5) and the scored sleep stage for the epoch in consideration (N_1) is 1 or 2 and neither a wake period nor one minute of REM occurs within 10 minutes.

IV. Criteria for Ordered Stage

A. Any stage 3 or 4 defines ordered stage 3-4

B. Any stage 2 occurring in ordered stage 2 or 1 defines ordered stage 2

C. Three consecutive epochs of REM in ordered stage 1 defines ordered stage REM (5)

D. One epoch of REM in ordered stages 3, 4, or 6, defines ordered stage REM (5)

E. If within fifteen minutes of a break in stage 3-4, another epoch of 3-4 occurs, ordered stage 3-4 prevails unless:

1. A wake period occurs

2. Two consecutive eopchs of REM occur

These situations define ordered stage 6 (Transitional)

F. A wake period is defined as ten consecutive minutes of wake (7).

Possible Sleep Scores for Epoch in Consideration (N_i)

Modified Adult Method:

N_i =

1	Stage 1
2	Stage 2
3	Stage 3
4	Stage 4
5	REM
6	Movement Time
7	Wake

Infant Method:

N_i =

1	Indeterminate
3	Quiet
5	REM
6	Movement Time
7	Wake

Possible Ordered Stage (J)

J =

1	Stage 1
2	Stage 2
3	Stage 3
4	Stage 4
5	REM
6	Transitional
7	Wake
8	REM Onset

START

Assume wake at beginning of recording. Sleep epochs must meet the criteria for beginning a cycle or REM onset before entering and ordered stage.

If epoch under consideration (N_i) is not scored the same as the preceding epoch (N_i - 1) [note: (N_i - 1) is always an ordered stage (J)]

The following decisions are possible:

1. N_i = 1
   a. J = 1 ==> continue J
   b. J = 2 ==> continue J
   c. J = 3-4
      1) Scan ahead 30 epochs (15 minutes) and look for REM (5) or 3-4
         - If within 15 minutes there are any eopchs of REM, J = 6 (Transitional)
         - If within 25 minutes there are either 10 minutes wake or one minute REM, J = 6 (Transitional)
         - If neither a wake period or a REM period occurs within 25 minutes begin new cycle, J = N_i = 1
         - If within 15 minutes there is any stage 3 or 4, continue J = 3-4
   d. J = REM (5)
      1) Scan ahead 10 minutes
         - If a wake period or REM (5) occur before 3-4, continue J = 5
         - If any stage 3-4 occur before wake or REM, begin new cycle J = N_i = 1
         - If neither of these two occur, begin new cycle, J = N_i = 1
   e. J = 6 ==> continue J = 6 Transitional
   f. J = 7 Wake
      1) Scan ahead 5 minutes
         - If there is any stage 3-4 in 5 minute period, begin new cycle and new period, J = N_i = 1
         - If three consecutive epochs of REM occur, J = 8 REM onset
         - If no more than one consecutive epoch of wake occurs, begin new cycle and new sleep period, J = N_i = 1
   g. J = 8 Same as d. above

2. If N_i = 2, scored epoch in consideration is stage 2
   a. J = 1, change ordered stage to J = 2
   All other cases of J same as N_i = 1 above

3. If N_i = 3 or 4, scored epoch is stage 3-4
   a. J = 1 or 2
      1) Scan ahead three minutes, if there is any stage 3-4, change J = 3-4
         - If not, continue J = 1 or 2
   b. J = 3 or 4, continue J = J
   c. J = REM, begin new cycle J = 3-4
   d. J = 6 (not likely) break in Transitional, continue J = 6
   e. J = 7 Same as 1.f
   f. J = 8 Begin cycle, J = N_i = 3-4

4. If N_i = 5, epoch scored as REM
   a. J = 1-2
      - If there are three consecutive epochs of REM, J = N_i = 5
   b. J = 3-4, begin REM J = N_i = 5
   c. J = 5, continue J = 5
   d. J = 6, begin REM J = N_i = 5
   e. J = 7 Same as 1.f
   f. J = 8, continue J = 8 (REM Onset)

5. N_i = 6, epoch is scored Movement Time
   Continue J = J for all J

6. N_i = 7, epoch is scored wake
   a. J = 7, continue wake, J = 7
   b. J = 7
      - If ten consecutive minutes of stage 7 wake, end cycle and sleep period, J = N_i = 7
      - If not ten consecutive minutes of wake, continue J = J

APPENDIX V

CONTINGENCY TABLES OF POLYGRAPH AND VIDEO SCORINGS

CONTINGENCY TABLE
OF
POLYGRAPHIC AND VIDEO SCORINGS
(MINUTES)

THREE-WEEK OLDS

Polygraphic States:	Video States: QS	AS	AWAKE	OUT-OF-CRIB	TOTAL
QS	493	127			620
INDETERMINATE	41	110		13	164
TRANSITIONAL	17	83	3		103
REM	24	620	13	29	686
AWAKE	5	50	222	272	549
TOTAL	580	990	238	314	2122

CONTINGENCY TABLE
OF
POLYGRAPHIC AND VIDEO SCORINGS
(MINUTES)

THREE-MONTH OLDS

Polygraphic Stages:	Video States: QS	AS	AWAKE	OUT-OF-CRIB	TOTAL
NREM STAGE 1	20	96	3	19	138
STAGE 2	353	136			489
STAGE 3	248	15			263
TRANSITIONAL	8	39			47
REM	1	490	10	19	520
AWAKE		20	162	47	229
TOTAL	630	796	175	85	1686

CONTINGENCY TABLE
OF
POLYGRAPHIC AND VIDEO SCORINGS
(MINUTES)

FOUR-AND-ONE-HALF MONTH OLDS

Polygraphic Stages:	Video States: QS	AS	AWAKE	OUT-OF-CRIB	TOTAL
NREM STAGE 1	181	275	10		466
STAGE 2	395	102			497
STAGE 3	346	22	1		369
TRANSITIONAL	19	52			71
REM	45	706	38		789
AWAKE	1	22	521	68	612
TOTAL	987	1179	570	68	2804

CONTINGENCY TABLE
OF
POLYGRAPHIC AND VIDEO SCORINGS
(MINUTES)

SIX-MONTH OLDS

Polygraphic Stages:	Video States: QS	AS	AWAKE	OUT-OF-CRIB	TOTAL
NREM STAGE 1	167	126	6	1	300
STAGE 2	292	147			439
STAGE 3	174	17			191
TRANSITIONAL	38	38			76
REM	42	458	4	5	507
AWAKE	7	30	178	96	311
TOTAL	720	816	188	102	1826

APPENDIX VI

POLYGRAPHIC AND VIDEO DATA

TOTAL NUMBER OF AWAKENINGS

Age(wks)	Infant	Polygraph	Video
3	Fr	3	4
	Hi	5	3
	Jo	3	5
12	Bi	10	8
	Bu	2	1
	Ga	2	1
18	Bx	5	3
	Es	7	10
	Ri	5	4
	Wa	11	7
24	Lu	4	7
	Pi	6	5
	Ta	3	3

$\overline{P} = 5.07$ $\overline{V} = 4.62$

$M = 4.84$

$r_{p.v} = .712$

NUMBER OF QUIET SLEEP ONSETS

Age(wks)	Infant	Polygraph	Video
3	Fr	0	0
	Hi	0	0
	Jo	0	1
12	Bi	8	0
	Bu	0	0
	Ga	1	0
18	Bx	5	0
	Es	2	1
	Ri	2	1
	Wa	7	1
24	Lu	2	0
	Pi	4	2
	Ta	1	2

$\overline{P} = 2.64$ $\overline{V} = .615$

$M = 1.54$

$r_{p.v} = .148$

NUMBER OF ACTIVE SLEEP ONSETS

Age(wks)	Infant	Polygraph	Video
	Fr	3	3
3	Hi	4	2
	Jo	2	2
	Bi	3	9
12	Bu	3	2
	Ga	0	0
	Bx	1	4
	Es	6	10
18	Ri	3	3
	Wa	4	6
	Lu	2	7
24	Pi	2	1
	Ta	2	1
		$\overline{P} = 2.69$	$\overline{V} = 3.85$

$M = 3.269$

$r_{p.v} = .602$

PERCENT QUIET SLEEP (proportion of total time in crib)

Age(wks)	Infant	Polygraph	Video
3	Fr	40.8	33.8
	Hi	26.1	29.8
	Jo	37.8	32.9
12	Bi	47.5	29.6
	Bu	56.9	44.7
	Ga	60.5	46.0
18	Box	46.9	25.4
	Es	49.1	39.9
	Ri	52.3	41.9
	Wa	46.8	38.7
24	Lu	54.0	26.7
	Pi	56.1	50.1
	Ta	51.4	48.0

$\overline{P} = 48.169$ $\overline{V} = 37.500$

$M = 42.835$

$r_{p.v} = .569$

PERCENT ACTIVE SLEEP (proportion of total time in crib)

Age(wks)	Infant	Polygraph	Video
	Fr	47.2	57.3
3	Hi	57.2	52.1
	Jo	43.8	55.6
	Bi	28.0	47.4
12	Bu	41.5	53.4
	Ga	33.7	48.3
	Bx	21.8	43.3
	Es	34.2	39.7
18	Ri	32.0	43.0
	Wa	39.5	46.8
	Lu	32.9	63.5
24	Pi	35.2	41.5
	Ta	32.7	37.2
		$\overline{P}$ = 36.90	$\overline{V}$ = 48.39

M = 42.646

$r_{p.v}$ = .445

PERCENT AWAKE (proportion of total time in crib)

Age(wks)	Infant	Polygraph	Video
3	Fr	12.0	8.9
	Hi	16.6	18.1
	Jo	18.4	11.5
12	Bi	24.5	23.0
	Bu	1.6	2.0
	Ga	5.8	5.8
18	Bx	31.3	31.3
	Es	16.7	20.4
	Ri	15.7	15.1
	Wa	13.8	14.6
24	Lu	13.1	9.7
	Pi	8.7	8.4
	Ta	15.8	14.8
		$\overline{P} = 14.92$	$\overline{V} = 14.12$

$M = 14.523$

$r_{p.v} = .944$

LONGEST SUSTAINED SLEEP PERIOD (minutes) [1]

Age(wks)	Infant	Polygraph	Video
3	Fr	185	185
	Hi	225	224
	Jo	141	148
12	Bi	188 (227)	232 (404)
	Bu	197 (557)	391 (555)
	Ga	193 (216)	215
18	Bx	137 (272)	271
	Es	420 (446)	159 (422)
	Ri	397	398
	Wa	134 (210)	203
24	Lu	162 (199)	156 (199)
	Pi	273 (288)	291
	Ta	209	208

$\overline{P}$ = 220.08 (272.77) $\overline{V}$ = 237.00 (286.38)

M = 228.54 (280.58)

$r_{p.v}$ = .298 (.913)

[1]Numbers in parentheses reflect LSP between awakenings $\geq$ 5 minutes. If omitted, the value is the same.

FIRST COMPLETE QUIET SLEEP PERIOD (minutes)

Age(wks)	Infant	Polygraph	Video
	Fr	23	25
3	Hi	21	24
	Jo	27	22
	Bi	33	33
12	Bu	33	33
	Ga	30	25
	Bx	17	11
	Es	32	34
18	Ri	29	19
	Wa	40	34
	Lu	39	40
24	Pi	46	96
	Ta	36	44
		$\overline{P}$ = 31.23	$\overline{V}$ = 33.85

M = 32.54

$r_{p.v}$ = .799

SLEEP CYCLE DURATION (minutes)

Age(wks)	Infant	Polygraph	Video
	Fr	48.7	50.6
3	Hi	60.3	64.3
	Jo	57.7	71.8
	Bi	54.6	61.2
12	Bu	62.0	62.6
	Ga	53.0	56.0
	Bx	42.0	49.1
	Es	58.4	52.0
18	Ri	47.6	48.4
	Wa	56.3	48.2
	Lu	42.5	45.6
24	Pi	55.1	66.3
	Ta	52.0	46.5
		$\overline{P}$ = 53.1	$\overline{V}$ = 55.6

M = 53.34

$r_{p.v}$ = .610

APPENDIX VII

HOME AND LABORATORY DATA

PERCENT QUIET SLEEP (TRP)

Age(wks)	Infant	Laboratory	Home
	Fr	29.9	32.2
3	Hi	24.2	40.0
	Jo	28.7	43.9
	Bi	29.2	44.4
12	Bu	44.7	36.9
	Ga	39.0	45.5
	Bx	24.6	25.4
	Es	38.2	39.1
18	Ri	40.0	41.5
	Wa	38.7	44.9
	Lu	25.6	25.5
24	Pi	48.7	42.4
	Ta	43.3	29.1
		$\overline{L}$ = 35.06	$\overline{H}$ = 37.75

r_1 = .159

PERCENT ACTIVE SLEEP (TRP)

Age(wks)	Infant	Laboratory	Home
3	Fr	50.6	57.6
	Hi	42.3	47.3
	Jo	48.6	37.6
12	Bi	46.7	54.0
	Bu	53.4	53.3
	Ga	41.0	52.2
18	Bx	42.0	57.0
	Es	38.9	44.2
	Ri	41.0	52.1
	Wa	46.8	44.2
24	Lu	60.9	64.9
	Pi	40.4	48.7
	Ta	33.5	21.1
		$\overline{L}$ = 45.08	$\overline{H}$ = 48.78

r_1 = .540

PERCENT AWAKE (TRP)

Age(wks)	Infant	Laboratory	Home
	Fr	7.9	2.0
3	Hi	14.7	4.2
	Jo	10.0	13.7
	Bi	22.7	1.6
12	Bu	2.0	5.1
	Ga	4.9	2.4
	Bx	30.4	14.5
	Es	20.0	7.2
18	Ri	14.5	4.5
	Wa	14.7	10.9
	Lu	9.3	6.0
24	Pi	8.1	7.2
	Ta	13.3	5.4
		$\overline{L}$ = 13.27	$\overline{H}$ = 6.52

r_1 = .264

PERCENT OUT-OF-CRIB (TRP)

Age(wks)	Infant	Laboratory	Home
3	Fr	11.7	8.2
	Hi	18.8	8.5
	Jo	12.6	4.8
12	Bi	1.3	0
	Bu	0	4.7
	Ga	15.1	0
18	Bx	3.0	3.1
	Es	1.9	9.5
	Ri	4.5	1.9
	Wa	0	0
24	Lu	4.1	3.6
	Pi	2.8	1.8
	Ta	9.8	44.3

$\overline{L} = 6.58$ $\overline{H} = 6.95$

$r_1 = .315$

TOTAL NUMBER OF AWAKENINGS

Age(wks)	Infant	Laboratory	Home
	Fr	4	2
3	Hi	3	3
	Jo	5	4
	Bi	8	0
12	Bu	1	1
	Ga	1	0
	Bx	3	4
	Es	10	1
18	Ri	4	1
	Wa	7	3
	Lu	7	5
24	Pi	5	2
	Ta	3	2
		$\overline{L} = 4.69$	$\overline{H} = 3.08$

$r_1 = .142$

TOTAL SLEEP TIME (minutes)

Age(wks)	Infant	Laboratory	Home
	Fr	552	571
3	Hi	571	565
	Jo	447	529
	Bi	465	565
12	Bu	553	562
	Ga	408	496
	Bx	517	454
	Es	566	564
18	Ri	555	503
	Wa	528	482
	Lu	510	575
24	Pi	547	608
	Ta	479	333
		$\overline{L}$ = 515.23	$\overline{H}$ = 523.62

r_1 = .286

LONGEST SUSTAINED SLEEP PERIOD (minutes)

Age(wks)	Infant	Laboratory	Home
	Fr	185	225
3	Hi	224	426
	Jo	148	233
	Bi	232	567
12	Bu	391	415
	Ga	215	496
	Bx	271	309
	Es	159	519
18	Ri	398	316
	Wa	203	262
	Lu	156	321
24	Pi	291	359
	Ta	208	279
		$\overline{L}$ = 237.0	$\overline{H}$ = 363.6

r_1 = .308

SLEEP CYCLE DURATION (minutes)

Age(wks)	Infant	Laboratory	Home
	Fr	50.6	72.6
3	Hi	64.3	60.8
	Jo	71.8	48.8
	Bi	61.2	57.2
12	Bu	62.6	61.0
	Ga	56.0	56.8
	Bx	49.1	60.5
	Es	52.1	52.4
18	Ri	48.4	54.0
	Wa	48.2	66.2
	Lu	45.6	38.2
24	Pi	66.3	58.1
	Ta	46.4	57.3
		$\overline{L}$ = 55.58	$\overline{H}$ = 57.23

r_1 = .055

MINUTES OF THE LONGEST SLEEP PERIOD IN 12-5 AM (%)

Age(wks)	Infant	Laboratory	Home
	Fr	.12	.25
3	Hi	.31	.87
	Jo	.49	.51
	Bi	.65	1.00
12	Bu	1.00	.98
	Ga	.31	1.00
	Bx	.41	.99
	Es	.06	1.00
18	Ri	.24	.56
	Wa	.68	.33
	Lu	.52	.69
24	Pi	.58	.75
	Ta	.69	.31
		$\overline{L}$ = .47	$\overline{H}$ = .71

$r_1 = -.138$

BEDTIME (i.e., 8:30 PM = 20.5)

Age(wks)	Infant	Laboratory	Home
	Fr	21.5	21.5
3	Hi	19.0	21.3
	Jo	22.2	21.6
	Bi	20.6	20.7
12	Bu	21.0	21.2
	Ga	22.0	22.2
	Bx	20.1	22.7
	Es	19.4	20.6
18	Ri	18.6	21.4
	Wa	20.6	23.0
	Lu	21.5	20.4
24	Pi	20.9	20.4
	Ta	19.6	20.9
		$\overline{L}$ = 20.54	$\overline{H}$ = 21.36

r_1 = .091

RISETIME (i.e., 7:30 AM = 7.5)

Age(wks)	Infant	Laboratory	Home
	Fr	8.9	8.0
3	Hi	9.3	8.0
	Jo	7.8	8.4
	Bi	6.5	6.1
12	Bu	6.3	7.4
	Ga	6.4	6.3
	Bx	8.4	7.1
	Es	7.1	7.6
18	Ri	5.9	6.3
	Wa	6.8	7.7
	Lu	7.2	6.9
24	Pi	6.9	7.0
	Ta	5.7	7.5
		$\overline{L}$ = 7.17	$\overline{H}$ = 7.25

r_1 = .543

TRANSITION PROBABILITY INDEX

Age(wks)	Infant	Laboratory	Home
	Fr	2.4	5.2
3	Hi	3.9	8.1
	Jo	2.2	10.0
	Bi	6.9	15.5
12	Bu	12.3	14.0
	Ga	5.7	13.3
	Bx	5.9	5.6
	Es	4.7	13.2
18	Ri	8.2	10.0
	Wa	8.3	9.6
	Lu	4.3	4.4
24	Pi	4.7	7.2
	Ta	4.2	5.8
		$\overline{L}$ = 5.67	$\overline{H}$ = 9.38

r_1 = .499

HOLDING TIME INDEX

Age(wks)	Infant	Laboratory	Home
	Fr	6.9	5.6
3	Hi	10.8	14.1
	Jo	4.0	19.2
	Bi	13.2	5.2
12	Bu	18.0	16.3
	Ga	11.4	6.5
	Bx	7.8	7.8
	Es	15.8	10.3
18	Ri	9.6	8.8
	Wa	11.8	12.1
	Lu	12.2	2.4
24	Pi	11.1	11.2
	Ta	18.9	16.0
		$\overline{L}$ = 11.65	$\overline{H}$ = 10.42

r_1 = .066

APPENDIX VIII

NIGHT-TO-NIGHT STABILITY DATA

PERCENT QUIET SLEEP

Infant		Night 1	Night 2	Night 3
An		34.1	43.2	52.6
Co		39.9	46.7	49.2
Cx		42.1	35.1	40.8
Cr		49.3	42.6	34.5
De		46.3	44.7	42.4
Gi		41.5	39.9	51.2
He		38.6	41.3	38.7
Ja		42.7	37.8	40.4
Li		38.7	40.8	40.1
My		43.9	38.8	41.2
Ne		40.6	45.0	60.1
Ri		36.0	44.8	39.0
Sl		33.1	45.6	33.4
Te		42.7	48.2	49.1
Za		38.4	43.1	43.4
	Median	40.6	43.1	41.2
	(Range)	33.1 - 49.3	35.1 - 48.2	33.4 - 60.1

PERCENT ACTIVE SLEEP

Infant	Night 1	Night 2	Night 3
An	60.2	53.0	41.1
Co	42.7	40.3	45.4
Cx	44.9	54.3	49.9
Cr	37.7	43.3	33.1
De	46.3	48.0	53.4
Gi	48.7	56.3	43.8
He	58.2	50.3	47.0
Ja	50.9	54.2	53.0
Li	48.4	45.8	53.1
My	47.6	54.4	49.2
Ne	36.7	45.6	32.7
Ri	57.0	54.2	60.2
Sl	50.7	45.9	55.1
Te	53.8	33.2	39.7
Za	50.3	50.0	50.5
Median	48.7	50.0	49.2
(Range)	36.7 - 60.2	33.2 - 56.3	32.7 - 60.2

PERCENT AWAKE

Infant		Night 1	Night 2	Night 3
An		5.7	3.8	6.4
Co		13.4	10.3	5.2
Cx		10.2	4.8	5.9
Cr		6.7	2.3	14.5
De		4.6	5.5	1.1
Gi		6.5	3.8	5.0
He		1.6	3.9	9.0
Ja		6.4	8.0	6.6
Li		3.4	1.3	3.0
My		8.4	4.4	9.2
Ne		7.7	3.7	5.2
Ri		1.3	1.0	0.8
Sl		12.3	6.4	9.0
Te		1.3	14.7	8.4
Za		7.3	3.2	2.1
	Median	6.5	3.9	5.9
	(Range)	1.3 - 13.4	1.0 - 14.7	0.8 - 14.5

PERCENT OUT-OF-CRIB

Infant		Night 1	Night 2	Night 3
An		0.0	0.0	0.0
Co		3.9	2.6	0.0
Cx		2.8	5.8	3.4
Cr		6.4	11.8	17.8
De		2.8	1.8	3.2
Gi		3.3	0.0	0.0
He		1.6	4.5	5.3
Ja		0.0	0.0	0.0
Li		9.6	12.1	3.8
My		0.0	2.3	0.0
Ne		15.0	5.8	2.0
Ri		5.7	0.0	0.0
Sl		3.9	2.2	2.5
Te		2.1	3.9	2.8
Za		4.0	3.7	3.0
	Median	3.3	2.6	2.5
	(Range)	0 - 15.0	0 - 12.1	0 - 17.8

TOTAL SLEEP TIME (MINUTES)

Infant	Night 1	Night 2	Night 3
An	492	479	545
Co	708	678	646
Cx	461	583	476
Cr	629	480	474
De	528	712	545
Gi	608	550	562
He	597	612	611
Ja	684	683	726
Li	491	599	563
My	694	716	672
Ne	541	612	465
Ri	555	581	496
Sl	643	588	644
Te	728	640	637
Za	672	631	676
Median	608	612	563
(Range)	461 - 728	479 - 716	465 - 726

MINUTES OF THE LONGEST SLEEP PERIOD IN 12-5 AM (%)

Infant	Night 1	Night 2	Night 3
An	.55	.69	.50
Co	.31	.17	.60
Cx	.58	.76	.57
Cr	.93	.38	.31
De	.70	.55	1.00
Gi	1.00	1.00	1.00
He	.70	.61	1.00
Ja	.93	1.00	1.00
Li	.67	.90	.66
My	1.00	1.00	1.00
Ne	.37	.00	.86
Ri	1.00	1.00	1.00
Sl	.00	.00	.29
Te	.87	.95	.01
Za	.55	1.00	1.00
Median	.70	.76	.86
(Range)	0 - 1.00	0 - 1.00	.01 - 1.00

LONGEST SUSTAINED SLEEP PERIOD (MINUTES)

Infant	Night 1	Night 2	Night 3
An	245	284	267
Co	402	362	258
Cx	231	227	223
Cr	352	188	248
De	265	382	359
Gi	422	557	562
He	357	234	442
Ja	605	683	713
Li	200	429	334
My	672	634	628
Ne	230	215	331
Ri	483	581	496
Sl	180	210	160
Te	536	311	261
Za	287	467	474
Median	352	362	334
(Range)	180 - 672	188 - 683	160 - 713

HOLDING TIME INDEX

Infant		Night 1	Night 2	Night 3
An		11.3	13.0	17.1
Co		12.8	8.6	7.0
Cx		13.8	14.1	11.9
Cr		19.7	15.8	14.9
De		15.6	12.1	9.2
Gi		11.2	15.1	19.0
He		6.1	7.6	13.6
Ja		8.5	13.5	16.8
Li		12.3	16.8	14.6
My		17.1	9.5	14.5
Ne		18.2	17.8	19.0
Ri		12.4	14.3	9.4
Sl		6.2	13.2	13.9
Te		14.4	19.3	17.7
Za		15.5	16.4	7.8
	Median	12.8	14.1	14.5
	(Range)	6.1 - 19.7	7.6 - 19.3	7.0 - 19.0

TRANSITION PROBABILITY INDEX

Infant	Night 1	Night 2	Night 3
An	8.9	11.9	9.4
Co	9.6	14.6	16.2
Cx	9.4	3.3	4.7
Cr	8.2	5.6	4.2
De	8.5	9.7	6.0
Gi	15.6	14.1	15.6
He	8.4	4.0	5.9
Ja	15.3	15.6	13.9
Li	4.1	10.6	6.1
My	14.5	13.3	14.0
Ne	4.8	4.4	7.6
Ri	7.9	14.2	14.5
Sl	3.4	8.0	3.0
Te	13.6	8.4	11.9
Za	9.2	14.9	16.0
Median	8.9	10.6	9.4
(Range)	3.4 - 15.6	3.3 - 15.6	3.0 - 16.2

BEDTIME (i.e., 8:30 = 20.5)

Infant	Night 1	Night 2	Night 3
An	22.5	22.6	22.0
Co	18.8	18.8	19.3
Cx	21.6	19.7	21.6
Cr	20.2	22.7	20.5
De	23.1	20.4	23.7
Gi	20.5	21.7	22.1
He	20.6	20.3	19.6
Ja	18.5	18.5	18.1
Li	22.8	20.1	21.7
My	19.1	19.4	18.8
Ne	19.6	19.8	22.8
Ri	21.2	21.6	23.1
Sl	19.0	19.7	18.8
Te	19.4	19.1	19.6
Za	18.4	19.2	18.7
Median	20.2	19.8	20.5
(Range)	18.4 - 23.1	18.5 - 22.7	18.1 - 23.7

RISETIME (hour: 6:30 = 6.5)

Infant		Night 1	Night 2	Night 3
An		7.2	6.8	7.6
Co		9.0	7.3	6.3
Cx		6.4	6.2	5.9
Cr		7.7	7.9	7.2
De		8.2	8.7	9.2
Gi		7.5	7.0	7.6
He		6.9	7.4	7.4
Ja		6.2	6.0	7.0
Li		8.0	7.7	7.5
My		7.4	7.8	6.7
Ne		7.0	6.8	7.1
Ri		7.2	7.2	7.4
Sl		6.9	6.3	6.2
Te		7.9	7.8	7.1
Za		6.5	6.4	6.4
	Median	7.2	7.2	7.1
	(Range)	6.2 - 9.0	6.0 - 8.7	5.9 - 9.2

SLEEP CYCLE DURATION (MINUTES)

Infant	Night 1	Night 2	Night 3
An	42.9	71.6	56.3
Co	51.3	52.6	41.9
Cx	58.5	54.1	45.7
Cr	57.1	47.8	46.8
De	67.0	57.4	62.3
Gi	49.8	65.9	45.5
He	56.1	43.2	60.4
Ja	47.2	58.2	63.1
Li	52.5	49.7	55.3
My	52.6	51.1	63.1
Ne	53.6	62.8	62.2
Ri	70.0	60.4	42.0
Sl	56.5	52.0	49.8
Te	50.0	54.6	47.1
Za	59.6	53.1	45.0
Median	53.6	54.1	49.8
(Range)	42.9 - 70.0	43.2 - 71.6	41.9 - 63.1

TOTAL NUMBER OF AWAKENINGS

Infant		Night 1	Night 2	Night 3
An		7	2	5
Co		4	3	3
Cx		2	4	2
Cr		2	2	5
De		1	1	2
Gi		1	0	0
He		2	4	3
Ja		1	0	2
Li		3	1	2
My		1	1	1
Ne		3	3	2
Ri		1	0	0
Sl		9	5	6
Te		1	2	4
Za		2	0	0
	Median	2	2	2
	(Range)	1 - 9	0 - 5	0 - 6

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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